Role of GIS in Assessment of Environmental Impacts of Coal Remining Sites in Ohio

A Thesis

Presented in Partial Fulfillment of the Requirements for Graduating with Honors Research

Distinction in the Undergraduate School of The Ohio State University

By

John C. Slone

Undergraduate Program in Civil Engineering

The Ohio State University

2013

Examination Committee:

Dr. Tarunjit S. Butalia

Dr. William E. Wolfe

Abstract

The objective of this study is to examine the role of a Geographic Information System (GIS), specifically ArcGIS, in investigating the environmental impacts of remining at a watershed level in Ohio. Since the passage of the Surface Mining Control and Reclamation Act (SMCRA) some remining has occurred in Ohio. Remining is the mining of surface mine lands and coal refuse piles that were abandoned prior to the enactment of SMCRA in 1977. It is a challenge to determine the environmental impacts of this remining. In this study, I have explored in detail how ArcGIS can be used as a tool for studying these impacts. In my study I have used a GIS-based methodology and have found various advantages that ArcGIS offers to augment the research efforts. The four main abilities/tools that I have found ArcGIS to offer are: spatial georeferencing, digitizing, centralization of data, and visual interpretation of data. A streamlined method has been presented to calculate the area of mine land that has been remined in a watershed. My study used the Duck Creek Watershed in south east Ohio as a case study.

Acknowledgements

I would like to thank Dr. Tarunjit Butalia for encouraging me to pursue completing this thesis when I thought there was no way possible that I would be able to do finish when evaluating my workload this quarter. There was a moment during the course of this year when I approached him to inform his that I did not think that I could finish a thesis and he kindly convinced me that I should finish it. I am thankful for having a research advisor that is truly concerned for my well-being. This has been a rewarding experience and I cannot thank him enough for his guidance and encouragement over the past year. I would also like to thank Dr. William Wolfe also for his encouragement to write this thesis because it is indeed, as he said in a lunch meeting over the year, something that I done that will stick with me forever. I would like to thank Bob Baker also who has been a pleasure to work for and has taught me so much about the Coal Industry and life in general. I would like to thank Liz Riter for always being there to take care of me during the application process and to look out for me and helping me catch all the deadlines. I would also like to thank Deepak Saluru for his assistance this year and being an amazing friend. I would like to thank Nathan Sparks for being an amazing person to work with in the lab. I would like to thank Cindy Luu for her artistic help on my Presentation slides. This would not be possible without any of you all.

Table of Contents

List of Figures

List of Tables

<u>Chapter 1 – Introduction</u>

1.1 Background

Since the passage of modern day coal mining laws over 38 years ago in Ohio, remining has played an important role in watershed restoration. However, this restoration activity has not been well documented in the state. Coal remining is the mining of surface mine lands and coal refuse piles that were abandoned prior to the enactment of the Surface Mining Control and Reclamation Act (SMCRA) in 1977. When coal operators remine abandoned mine sites they must adhere to modern mining laws and fully reclaim the land back to its approximate original appearance. In recent years new coal mine permitting has become increasingly more difficult with the regulatory reviews associated with obtaining federal and state permits. Studying the impact remining has at a watershed level is important and unprecedented in Ohio and can serve as valuable background information for regulators involved in permitting activity as well as the general public. It is also important for Ohio Department of Natural Resource's Division of Mineral Resources Management (DMRM) to effectively administer the remining program and provide for a seamless permitting system which facilitates remining of coal reserves. During remining operations, acid-forming materials are removed with the extraction of coal and the abandoned mine land is reclaimed.

Studying the impact that remining has on the landscape can be difficult to measure. It can be beneficial to develop a method in order to quantitatively measure the impact that remining has on a watershed. The use of Geographic Information Systems (GIS), specifically ArcGIS, has allowed me to provide this type of analysis. The use of ArcGIS and its many capabilities have greatly assisted in my research efforts of investigating the environmental impacts remining has on the coal bearing regions of Ohio.

1.2 Research Objective

The objective of this study is to examine the role of implementing a GIS, specifically ArcGIS, for watershed assessment of environmental impacts of coal remining in Ohio. I plan to highlight the advantages and applications of ArcGIS and how it can be used to assist in the environmental assessment of the Duck Creek Watershed as a case study. The reasoning behind selecting the Duck Creek Watershed is because the watershed has been adversely affected by coal mining through a number of factors including Acid Mine Drainage (AMD). There are many advantages of using ArcGIS to assist my study. A few of these advantages include spatial georeferencing in ArcGIS, digitizing in ArcGIS, and projecting data through the production of maps through ArcGIS.

There are a number of benefits of this study. By examining the role of implementing a GIS, one can explore the capabilities of software like ArcGIS in analyzing Land Use Land Cover (LULC) changes in a region that has been surface mined. This study can help other researchers whose work can possibly be augmented by using GIS.

1.3 Summary of Thesis

This thesis is organized as follows. Chapter 2 contains a literature review of those that have performed significant prior work related to this research. Chapter 3 outlines the methodology used in the research that has been performed over the past year. Chapter 3 contains a brief overview of GIS, specifically ArcGIS, and its role in the research performed in investigating the role that remining has played in the mitigation of environmental impacts due to coal mining. Chapter 4 contains the results of this research and explains in detail how certain applications of ArcGIS have tremendously aided researchers in their investigation. Chapter 5 concludes with a summary of ArcGIS's role in the work performed and provides a discussion of future proposed work.

1.4 History of Coal Mining in Ohio

Ohio has a rich history of coal mining. Surface mining was first reported in 1810 in Summit County. The early surface mines excavated coal veins exposed on the outcrop of hillsides. Surface mining became the dominate method of coal extraction until 1995 when it was overtaken by underground mining. Surface land is disturbed in the process of mining, where topsoil, subsoil, and overburden as well as rock layers above the coal are removed to access and remove the coal reserve. This material following excavation is called mine spoil and the floor of the excavation leaves a steep highwall where mining ceased. These highwalls generally range from 30 to 90 feet in the Noble county area. Although the affected areas range in size from a few acres to hundreds of acres the impacts of unregulated or inadequately regulated mining can be far reaching in terms of ecological and environmental damage, resulting in streams choked by sediment, acid mine drainage (AMD), landslides, and subsidence (Crowell,1987).

In Noble County Ohio, the Ohio Geological Survey (OGS) records indicate that underground mining began in 1845, but about 18 million tons of coal was mined by this method prior to the advent of surface coal mining in 1944. From 1944 until the modern day reclamation law was passed in Ohio in 1972, approximately 46 million tons of coal were surface mined in Noble County. From 1944 to 1972 an additional 18 million tons of coal were underground mined bringing the total of underground mining to about 36 million tons. Surface coal mining tonnage from 1944 to 1972 exceeded underground production by 22% during this period. In summary, surface mining was the dominant form of coal extraction in Noble County during this period and currently is the only form of coal extraction and has dominated production in Noble County since 1947 (Crowell, 1987) .

Before mining takes place a surface mining permit (Ohio Revised Code 1513) must be obtained from the Ohio Division of Mineral Resources Management (DMRM, formally known as the Division of Reclamation). Until 1947 surface mining was unregulated in Ohio. Coal companies were not required to reclaim the land following mining. During this era, reclamation was not considered to be practical from an economic perspective. The price of coal delivered to market did not support reclamation activities at that time. In 1949 the Ohio Division of Reclamation was created and was coupled with the Ohio Division of Forestry until 1973. During this time frame reforestation was the main focus of reclamation. From 1949 until 1972, Ohio's mining law was amended several times, although the laws and amendments were an improvement they were still ineffective in preventing pollution to the waters of the state and in restoring the land to a higher or equal land use prior to mining. A law revision in 1965, created the first series of permits that were labeled A-Permits. Areas affected prior to the 1965 amendments were labeled pre-A permits. Although, the amendments generally required the areas to be reforested, highwalls generally remained intact. The A-law amendments did require pits to be filled in and some drainage was provided.

In 1972, Ohio passed the most stringent and rigorous surface mine law in the country. This law required mine operators to save topsoil, backfill highwalls, control runoff, reclaim and revegetate all affected areas, and minimize impacts to the hydrologic regime. The coal permits issued during this period were labeled B-permits. The legislation created the "Board on Unreclaimed Strip Mines" which immediately commissioned a study to assess the impact past mining had on Ohio's Coal mine regions prior to 1972. This report was titled "Land Reborn", and together with the associated technical report presented a comprehensive benchmark of the state of the land and waters impacted by past unregulated mining. The report indicated that at the time the report was completed in 1973 the west fork of Duck Creek was affected by surface mining in the amount of about 7,600 acres or 7.6% of the watershed, and East and Middle Forks of Duck Creek incurred about 9,000 acres of surface mining or 10.4% of the watershed. This 1972 Ohio law served as one of the models for the national legislation in 1977, titled "The Surface Mining Control and Reclamation Act of 1977" (SMCRA). This legislation required each state whose borders contained coal mining operations to meet or exceed the federal standards of reclamation or face federal takeover of the their respective mining programs. Ohio received primacy from the SMCRA regulatory authority, the Office of Surface Mining and Reclamation Enforcement (OSMRE) in 1979, and the permits issued after that time were labeled C- permits. After receiving primacy each state program became eligible to receive federal grants to correct the problems and impacts from past mining practices in their respective states.

This program is titled “The Abandoned Mined Land Program”, and has been operating in an effective manner in Ohio since 1979. These funds provide support for grants from the OSMRE to the states to operate and fund their respective abandoned mined land and regulatory mining programs, and a state administered abandoned mined land program.

Ohio DMRM’s website indicates that; 1) DMRM Staff engineers and project managers design and oversee the reclamation of a variety of hazardous or environmentally degrading mine-land problems, including mine openings, landslides, highwalls, erosion, toxic spoil, subsidence, and acid mine drainage, 2) The Federal AML Program is completely supported by federal grants derived from fees on coal mined in the U.S. The program emphasizes the elimination of health and safety hazards left by mining operations prior to May, 1977. A Federal Emergency Program has been created to expedite reclamation when an immediate danger exists. 3) A separately funded State AML Program, using funds from a severance tax on Ohio mine operators, completes environmental-reclamation projects in areas affected by mining prior to April, 1972. Reclamation is achieved by means of cost sharing, direct contracting, and state-initiated projects. When possible, acid soils or partially reclaimed land is reforested. Program staff members also work with active mine operators to encourage remining abandoned mine land to eliminate toxic lands and reduce acid mine drainage at limited or no cost to the state. 4) Through the Acid Mine Drainage (AMD) Abatement Program, the division assists public efforts to restore the quality of water resources in communities impacted by acid mine drainage. Partnerships are formed with watershed groups, government agencies, and private industry. The DMRM provides funding and implements construction projects to restore mine-impacted watersheds. (DMRM)

Administrative updates of the federal rules and other changes mandated on the states required states to change and update regulations ushering in the D permits in Ohio. This thesis references the various A through D permits and AML projects.

Chapter 2 - Literature Review

There has always been a need to quantify the amount of coal mining and remining that has occurred in the watershed. With the use of GIS being introduced in the 1990s, researchers, federal agencies, and industry experts wasted little time to explore ways to use this technology to analyze environmental qualities of watersheds that have been affected by coal mining.

A collaborative effort between University of Tokyo researchers and the UK's Institute of Hydrology conducted a study of the regional water quality of the Humber catchment, a section that includes the basin and all rivers entering the Humber, a large tidal estuary on the east coast of Northern England (Oguchi, 2000). In their study the regional water quality of the Humber catchment was mapped for key inorganic chemical determinants using a GIS system and an extensive Environmental Agency (EA) and Land-Ocean Interaction Study (LOIS) monitoring database. The use of GIS in their study allowed them to bring together for the first time all the EA and LOIS river quality data for the entire major UK rivers network draining into the Humber Estuary, using GIS-aided mapping and analysis. The study demonstrates how a complete centralization of data can be achieved and the benefits that can be reaped from the capabilities of GIS. This study benefited from the GIS software's mapping capabilities. The data that they collected and centralized in the GIS database was presented in the form of an atlas of water quality maps for the Humber catchment. The amount of trace elements was mapped and successfully displayed which sites in the catchment had the highest abundance of trace elements. The work done by Oguchi, 2000 is similar to mine in respect to the fact that it uses the capabilities of GIS to centralize all water quality and land data and display them through the utilization of ArcGIS's mapping capabilities. However, it differs in respect to the scope of the work. Their study was evaluating the major factors affecting the general characteristics of regional water quality. A few of sources for the high concentration of determinants include sewage, coal mine drainage (AMD), soil pollution caused by past ore mining, bedrock geology, the agricultural use of fertilizers, and the ingression of seawater into the estuary. My study deals specifically with the effects from coal remining and reclamation at a watershed level and focuses on the Duck Creek Watershed located in Southeast Ohio.

In May 2005 Dale Bruns from Wilkes University in Pennsylvania published a study investigating the macro-invertebrate response to land cover, habitat, and water chemistry in a mining-impacted river ecosystem. (Bruns, 2005) In this study, a GIS was used to investigate the land, and water impacts on a watershed scale. This study appears to be the first GIS watershed assessment of mining land use affects since, prior to this time, most published studies of land use impacts to watersheds and lotic ecosystems had focused on either agriculture or urbanization. Bruns studied these land changes using two critical tools to this broad-scale approach in environmental monitoring, assessment, and management: remote sensing and GIS. ArcGIS was used to input, store, retrieve manipulate, and analyze collected spatial information regarding watershed conditions relative to land cover, geomorphic, chemical, and macro-invertebrate parameters of water quality. For land use and land cover, a French SPOT satellite image was used for the summer of 1994, concurrent with field sampling for benthic substrates, water chemistry, and macro invertebrates. Code phase GPS was used to geo-reference the SPOT image and align classified features with other environmental data bases on the GIS. They also performed their own stream sampling and performed some statistical analysis on data collected. From using the methods described, the scientists were able to notice several trends when analyzing the watershed. Many of these trends relate to a few areas including the physical habitat, chemical parameters, and micro-invertebrates. One trend that they noticed that pertains to the research in his study is that the Alkalinity and pH were both at sufficiently high levels at all mining sites. Also, in general, acidity levels, turbidity, and concentrations of dissolved iron were highest in sub-catchments where mining was high or intermediate as a barren land cover class. The method used in my work differs in respect to how the land cover analysis was performed. Bruns used SPOT imagery and used technical and complicated techniques in order to analyze changes in land cover. I took an approach to do all of the land analysis through methods utilizing GIS software. Also, the study that Bruns performed only analyzed and classified data and streams using current data with no respect to changes over time. This is an important difference because in my work I have looked at long-term changes over time as well and short-term changes through analysis of permit data collected before and after mining. A few problems cited in their study included multiple scale-dependent mechanisms in delineating "pathways of influence" based on empirical analysis of land use and stream response. (Bruns, 2005) Another problem in studies that relate land use to stream response based on a GIS watershed analysis is the co-variation in both land cover classes and intermediate habitat factors such as benthic substrates and woody debris. These factors may not vary independently and bivariate correlation analyses of land use, nutrient, habitat parameters, and macro-invertebrate community response may yield numerous statistical findings that overestimate the importance of these relationships or result in spurious associations.

In 2011 Nathaniel Mauger (2010) completed a study in which he investigated coal remining in Ohio and the post-mining land use implications of remining policy. Mauger pursued to answer two looming questions. First, how can emerging geospatial technology (i.e. GIS) allow users to identify remining sites on the landscape and secondly how do operators and landowners decide between various revegetation options, and how do these revegetation regimes influence the choice of constructed land use by public and private institutions and local communities? (Mauger, 2010) In his study Mauger examined remining's place within the framework of political ecology. He wanted to see if remining and reconstruction are good practices that should be encouraged. The methodology that Mauger used is significant. As a student researcher for OSU's Department of Civil Engineering under the supervision of Tarunjit Butalia, Ph. D. and William Wolfe, Ph.D., he was able to develop a step by step GIS model for identifying remining sites that I was able to use in my study. This GIS method for identifying remined areas that he and his team developed can be used as a tool to quantify site level changes due to mining method as well as to provide a template through which future researchers will be able to isolate sites that have been strip mined before and after modern reclamation laws (Mauger, 2010). Mauger found that GIS was an indispensable tool for analysis of remining in Southeast Ohio. He was able to quantitatively analyze the impact that remining had at 3 remining sites in Southeast Ohio. By quantitatively it is meant that he was able to estimate the length of highwalls and the mining affected area. Through analysis using GIS, he was able to conclude that remining, through using proper Best Management Practices (BMPs) has had a positive impact on the environment in the coal bearing region of Southeast Ohio.

The difference between my study and Mauger's is that instead of focusing on the political or ecological perspective of remining, I aim to highlight ArcGIS's role in this process and analyze how ArcGIS has helped us from not so much from a geographical or political point of view but from a technological and engineering point of view. A method of analyzing remining in coal bearing regions has been developed. It can be beneficial if we dig deeper into how this fascinating technology can benefit researchers, operators, and government entities alike.

Chapter 3 – Methodology

The methodology used in this study was developed in response to a need to determine the amount of area that has been remined or the length of the highwall remined in a given watershed. This chapter is intended to give an overview of ArcGIS and to give a summary of how I used ArcGIS to investigate the environmental impacts of remining and how the methodology was developed.

3.1 ArcGIS Overview

There are dozens of definitions for the term geographic information system (GIS), each developed from a different perspective or disciplinary origin. Some focus on the map connection, some stress the database or the software tool kit, and others emphasize applications such as decision support. One of the most general definitions was developed by consensus among 30 specialists as: ***Geographic Information System** – A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth.* (Chrisman, 1997)

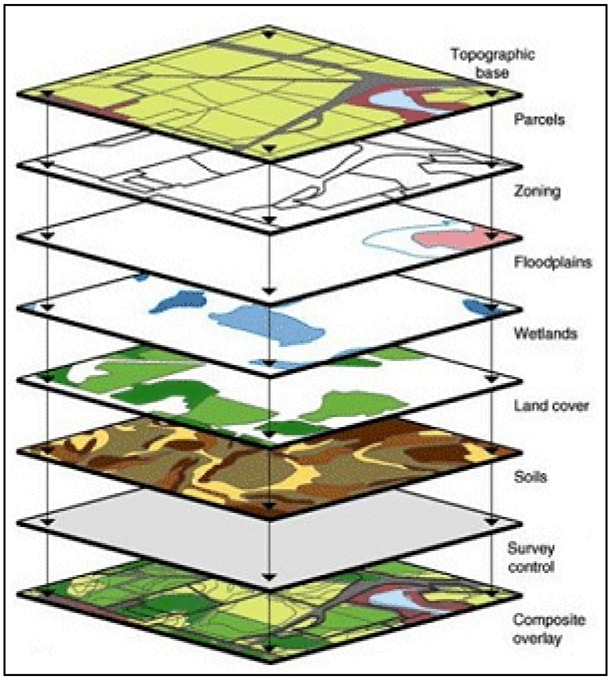


Figure 1: Organization of GIS in layers

I have used the ArcGIS software in my research work. ArcGIS is a Geographic Information System (GIS) that is a product of Environmental Sciences Research Institute (ESRI), one of the leading suppliers of GIS software and geo-database management applications. Other suppliers of GIS software include BREEZE Software and Data, Locus Technologies, and SoundPLAN International. (Environmental Expert S.L., 2013) The use of ArcGIS allows us to organize layers of data spatially for the purposes of data modeling, analysis, processing, and display. This organization of GIS layers is displayed in Figure 1. This feature allow us to quickly analyze and present data by selecting and deselecting which layers that we would like to be display at any given time.

There are two primary components of ArcGIS: ArcMap and ArcCatalog. ArcMap is an application for displaying maps and investigating them, for analyzing maps to answer geographic questions, and producing maps that make analysis persuasive (Ormsby, 2009). ArcMap is the venue where all the map-making work and analysis is performed. It works with the ArcCatalog to acquire the necessary data. ArcCatalog is an application for managing geographic data. One can copy, move, and delete data; search for data before deciding whether to add it to a map; and create new data sets. The ArcCatalog application window includes the catalog display for looking at spatial data, the catalog tree for browsing data, and several toolbars. Features must be created or added into ArcCatalog before being able to be used in ArcMap. Throughout this thesis these two terms are mentioned frequently and it is beneficial to be able to distinguish between them. In this work, one will see how ArcGIS has been an invaluable asset to research efforts investigating the impacts of remining.

3.2 Summary of Procedures Performed

Let us examine ArcGIS's role in our research efforts from a macroscopic perspective before digging into certain useful applications of ArcGIS and how they can be of benefit to a geographer, political ecologist, or engineer's analysis. In this work, I am using ArcGIS to investigate the impacts of reclamation and remining on watersheds of pre-law legacy coal mines. Specifically I have focused on Duck Creek Watershed since Mauger (2010) had laid the groundwork for this watershed.

Duck Creek (see Figure 2) is a tributary of the Ohio River located in Southeast Ohio and its confluence is located near the town of Marietta, Ohio. The 1974 Land Reborn study (Skelly and Loy, 1973) was commissioned by the board on unreclaimed strip mined lands to evaluate the condition of 79 watersheds in the coal bearing region of south east Ohio. The study classified each watershed as either low, medium, or high priority based on pollution loadings in rivers, creeks, and streams; the prevalence of abandoned mine lands; and the feasibility of proper reclamation and restoration of the watershed. The study indicated that of all 79 watersheds investigated, the Duck Creek Watershed was determined to be the highest priority watershed for reclamation in the state

Figure 2: The Duck Creek Watershed

In order to perform an analysis of remining in the Duck Creek Watershed, one needs a consistent and effective method of doing so. The student researcher who preceded me on this project, Nathaniel Mauger, had developed a step by step template for analyzing land impacts through ArcGIS (see Figure 4), which I used for my study.

a.) Collection of Information

First, in order to facilitate the calculation of the area and number of abandoned mine land features affected by remining, three National Aerial Photography Program (NAPP) aerial images captured circa 1975 were obtained. These images showed the landscape of the area before SMCRA was passed of all mined areas in Ohio. Other more detailed aerial photography taken of the places in the Duck Creek watershed were also obtained from coal mining operators, like B&N Coal Co., and other various sources. These images allowed me to locate highwalls and highwall pits present prior to the enactment of SMCRA. These highwalls and pits were then digitized and saved in a polygon feature class in ArcGIS. Of course, there are some challenges and limitations with respect to depending on the user's ability and judgment to decide what is a highwall or a pit because there are numerous aspects that can hinder the ability for the user to distinguish what is abandoned mine land and what is not. Forest regrowth is an example of one of these hindrances. In order to battle this hindrance, ODNR AMLIS (Abandoned Mine Land Inventory System) topographic maps as well as 7.5-minute topographic quadrangles for Ohio were used to confirm the locations of possible mine lands by comparing them with the areas on the topographic maps that represent strip mines (see Figure 3). Once I determined where an abandoned strip mine was, then I could consistently calculate the affected mine area with the aid of the topographic maps.

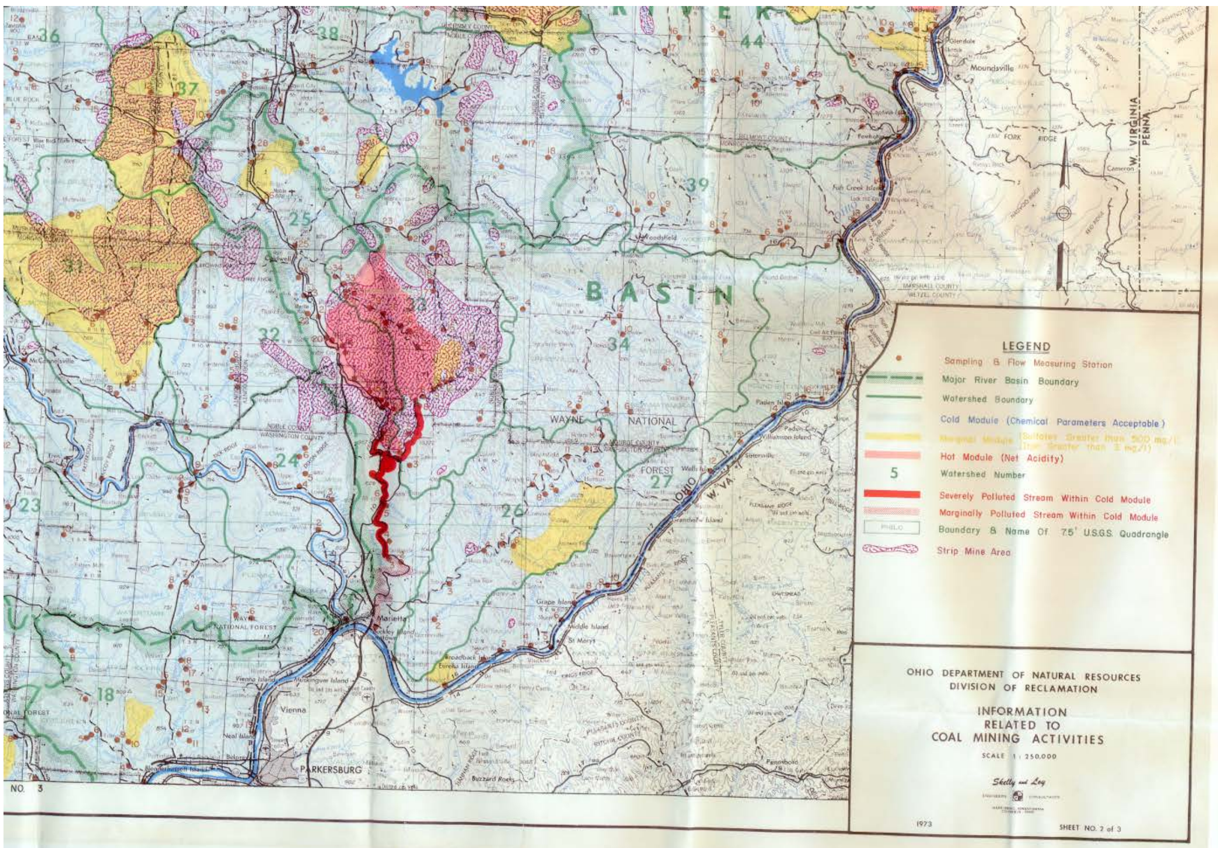


Figure 3: Historic Coal Mining Activity Map

b.) Data Storage

Once each feature was created and saved by the user in the ArcGIS database, each feature was then assigned a “tuple” or record within the database (Ormsby, 2009). Fields to store attributes such as polygon area, highwall length, and permit type were then created. Thus I created a pre-law highwall and area dataset stored spatially within the ArcGIS database. Next, I took advantage of ArcGIS's capabilities of using layers to display information. Modern relatively high-resolution aerial photography was provided as a base-map through ESRI (2009 National Agriculture Imagery Program Imagery). I was able to overlay pre-law highwall shapefiles onto 2009 ESRI Aerial Photography. This enabled me to review, analyze, and determine the current state of the abandoned mine land. If by visual inspection it was determined that a highwall or mining pit was present in the historic imagery and then the same location appears to be reclaimed in the 2009 imagery, then I determined and recorded the current reclamation status of pre-law highwalls/highwall pits. Each feature within the abandoned mine land database was given a classification based on reclamation progress. The classifications were simply represented as numbers 1, 2, and 3. They represented land to be determined as unreclaimed, partially reclaimed, and fully reclaimed respectively.

Once reclamation status was established, spatial data through shapefiles and maps detailing the extent of Ohio mine permits was acquired. This information was obtained through the Division of Mineral Resources Management's Geographic Information Management System (GIMS) database for use in GIS. (Mauger, 2010) These permits were used to determine the permit designation of highwalls and mining affected area features already stored in the database. There are four permit designations in the history of Ohio. These four permit types are A, B, C, and D permits. All evidence of mining does not necessarily overlap with one of the four permit designation. The different permit types are in chronological order from A to D. A-permits are issued earlier in time than D-permits. The permit designations correspond to the changes in the laws and requirements of coal mining through the years. B, C, and D permits are considered modern mining because they all occurred after the enforcement of SMCRA. Therefore, if the permit designation for a fully reclaimed mine site is B, C, or D, then the reclamation standards to a previously abandoned surface mine (pre-SMCRA) are applied by modern mine law and remining has occurred. If modern mining (B, C, or D permit designation) occurs where there was not determined historic mining then it was considered virgin mining.

c.) Data Analysis

The remining sites were now determined and stored as their own feature class in the geo-database. I then used basic statistic functions to determine important statistics such as remined area, eliminated highwall length, and how much abandoned mine lands are still in need of reclamation. I was able to determine the extent of state funded AML projects sites by implementing shapefiles produced by DMRM. I also determined which areas had been remined through limited reclamation techniques on abandoned mines using state funds. These funds come directly from the severance tax that coal operators have to pay in order to mine coal in the state of Ohio.

Once the remining features were determined then I manually determined and recorded the operator, application date, and permit number in pre-law shapefiles. That way all the relevant data was stored in one location which greatly facilitated the analysis on the streams as well as the land cover of the watershed. Knowing this information enabled me to have a greater idea of the time frame and the extent of the mining that had occurred in the area. Knowing the operator of the mining area allowed me to know who to contact for specific water quality (WQ) permit data for a more detailed evaluation of a specific mining site. The next step was to overlay a layer including the location of federally funded AML projects in order to eliminate non-remined reclaimed sites. An area where I noticed remining had occurred that overlapped with an AML project indicated where there was a collaborative effort between the state and industry (Mauger, 2010).

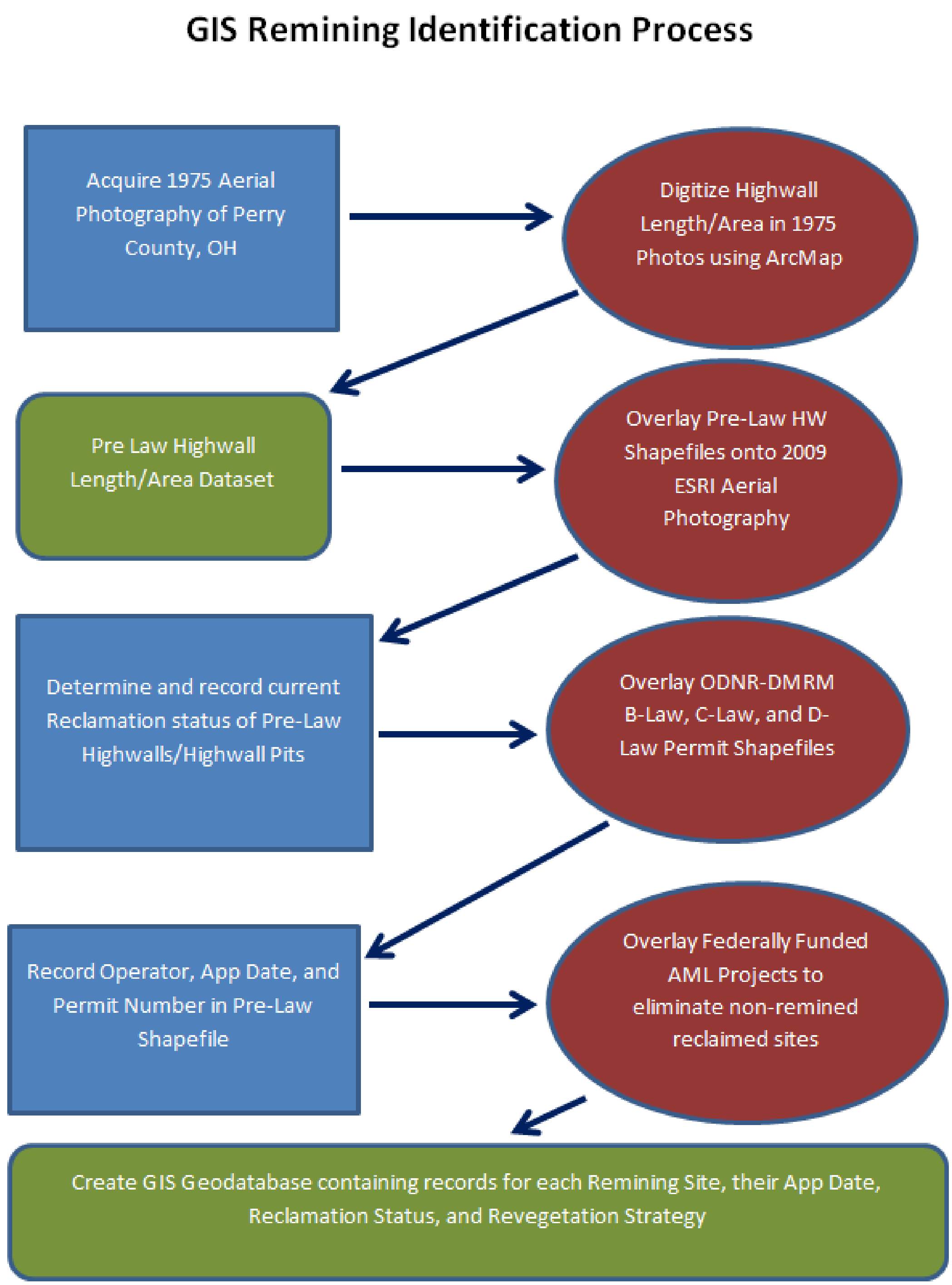


Figure 4: GIS Identification Process for Remined Lands (Mauger, 2010)

This procedure to evaluate the Land Use Land Cover (LULC) changes in the Duck Creek Watershed has proven to be an enormous asset in research efforts so far. This procedure can be used as a template to study remining anywhere in the world. My plan is to dig deeper into the ArcGIS tools and techniques that we used in this procedure and show how they have increased the quality of my research effort.

<u>Chapter 4 – Results: Applications of ArcGIS</u>

4.1 Spatial Georeferencing in ArcGIS

Georeferencing means relating information to geographic locations. It is a component of our lives and has been incorporated into information systems in various ways. The scope of georeferencing includes the informal means of referring to locations, which we use in ordinary discourse using place names, and the formal representations based on latitude and longitude coordinates, and other spatial referencing systems which we use in activities such as mapmaking and navigating. (Hill, 2006) In the case of analyzing remining in south east Ohio, I used aerial photography (historic and current), satellite imagery, and scanned maps acquired from the various government agencies and coal operators. Scanned map datasets do not contain spatial reference information. With aerial photography and imagery, sometimes the location information delivered with them is inadequate and the data does not align properly. Therefore, in order for me to use raster datasets along with the other spatial data that had already been loaded into the geo-database, I needed to align, or what is termed georeference, to a map coordinate system. A map coordinate system is defined using a map projection. The map projection that I used for all the data in my geo-database is WGS84.

Georeferencing images allowed the placement aerial images or scanned maps with no map coordinates assigned into a spatial environment with spatial qualities. When dealing with coal mining, one can expect to have to dig through old permit maps or USGS topographic maps. This is especially helpful when dealing with historic photos or scanned maps. This is how I used georeferencing in the research to geo-rectify a historic aerial photograph.

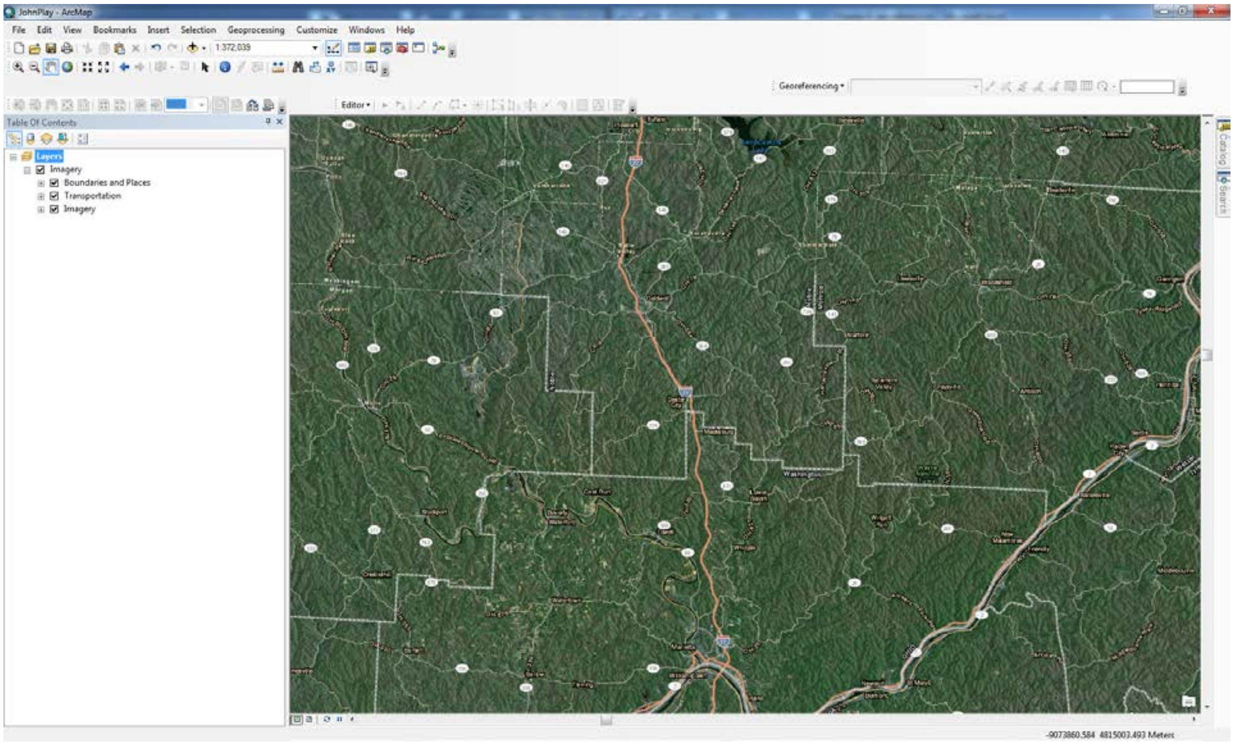


Figure 5: ArcMap shows 2009 ESRI imagery of Duck Creek Watershed

I used ESRI 2009 imagery (see Figure 5) provided through ESRI, the creators of ArcGIS, to connect the folder in ArcCatalog where the newer, more detailed aerial photographs are located. A screenshot showing ArcGIS open with the 2009 ESRI Imagery displayed is shown in Figure 5. The first step was to connect to the folder in ArcCatalog (see Figure 6) in order to be able to use the images in ArcMap.

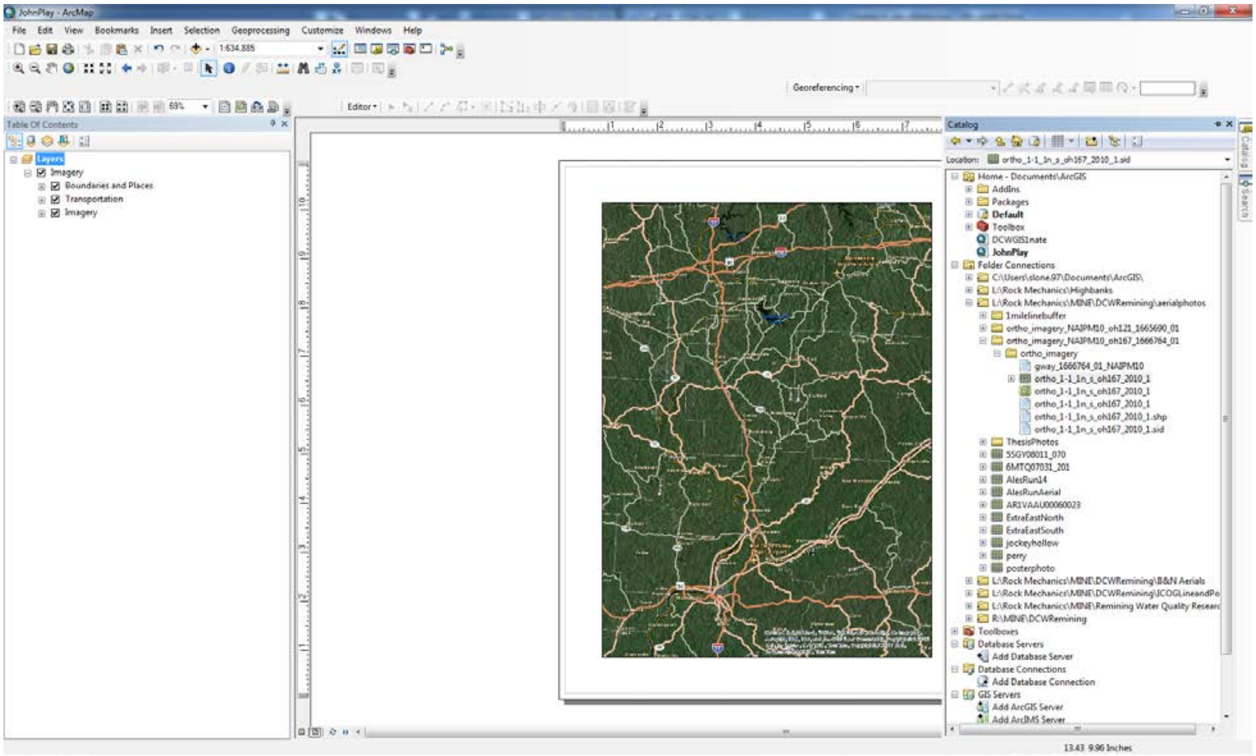


Figure 6: ArcCatalog Toolbox

Spatial data comes in many different formats including geo-databases, shapefiles, CAD (computer-aided design) files, rasters, and TINs (Triangular Irregular Networks). Each format is identified by its own icon in ArcCatalog. The 2010 aerial images were acquired from the NAIP (National Agriculture Imagery Program), which is a program where the USDA acquires aerial imagery during the agricultural growing seasons. This is a reliable source from which to acquire current aerial imagery.

Once I acquired the desired NAIP aerial imagery and had connected the folder it was located in, then all that needed to be done was the data needed to be "placed" into ArcMap. This process involved selecting and dragging the desired dataset over and placing it in the table of contents. Another way this can be performed is creating a layer right from the ArcCatalog window and storing the raster data in a feature layer instead of just a feature class.

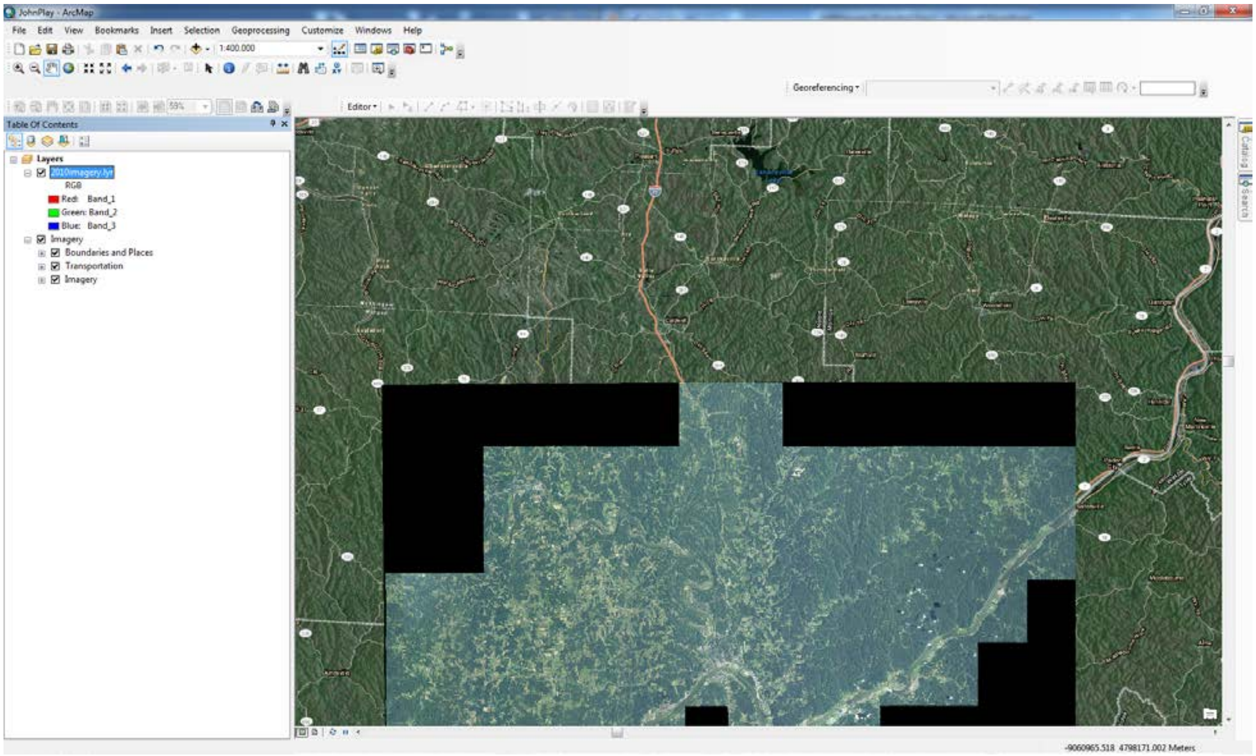


Figure 7: ArcMap with NAIP Imagery

One can see the result of this processing of data in Figure 7. The imagery is loaded immediately into ArcMap with its spatial location already correctly converted, determined, and displayed. This is possible because the NAIP imagery in form of a raster file already had coordinates assigned to them. However, the projection that the NAIP data was assigned to is UTM Zone 17 and the 2009 ESRI imagery already in ArcMap was projected off of a WGS 1984 coordinate system. A useful function of ArcGIS is that it will automatically perform transformation equations on any data loaded into the system. ArcGIS can convert all incoming data to the current datum that the system is in unless specified by the user. The warning dialog box in Figure 8 below appears when one loads data into ArcMap that is using a different coordinate system that one is currently in. If one clicks on the transformations button, then that takes the user to a dialog box (see Figure 9) where one can convert to the current coordinate system.

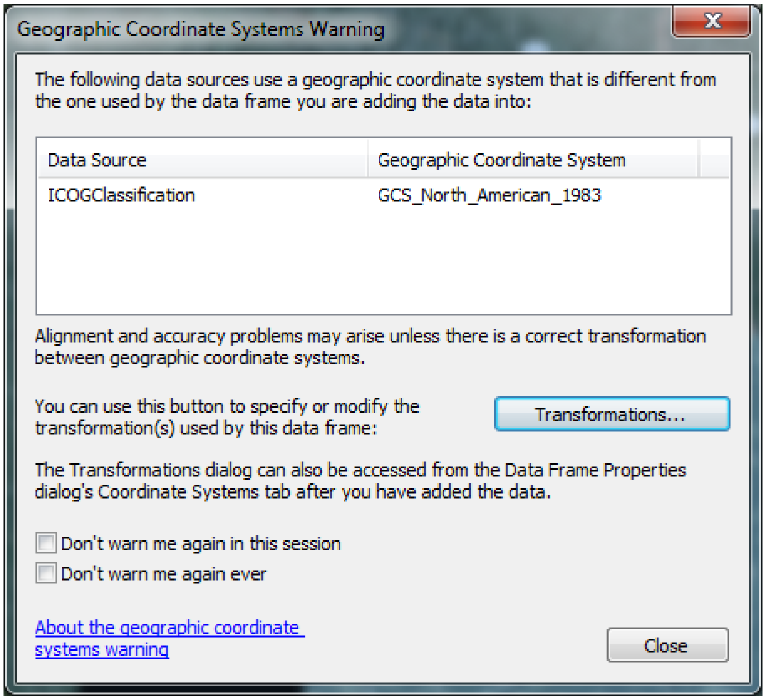


Figure 8: Geographic Coordinate Systems Warning Dialog Box

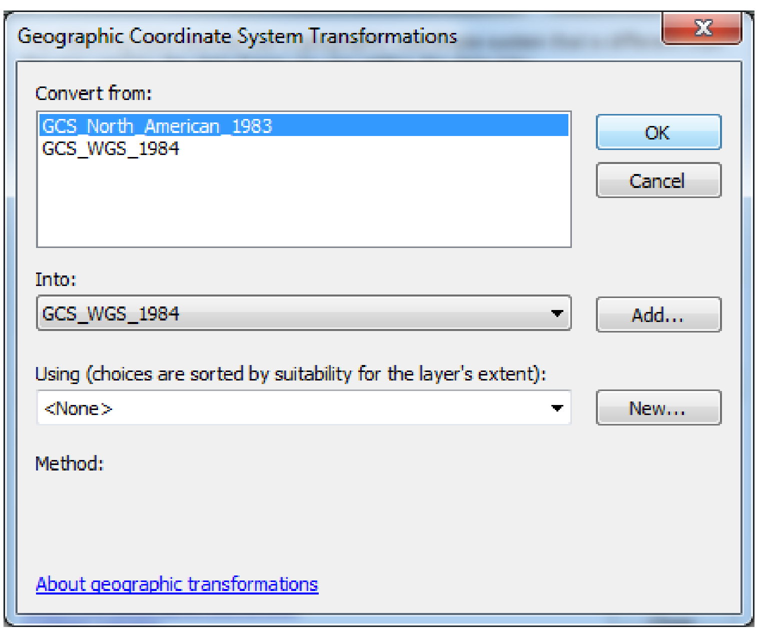


Figure 9: Geographic Coordinate System Transformation Dialog Box

Now that the 2010 aerial photograph is loaded into the ArcMap, one needs to load historic aerial photography to compare it to. This is the best method of comparing visual changes over a period of time. Once the user has obtained historic aerial imagery it can then be loaded into ArcMap using a similar method as the 2010 NAIP imagery. While some historic aerial photography has a reference system applied to it, the user will often find that the aerial photography that is wished to be used does not have a defined reference system. In this case it is necessary to relate the raster data in the feature class to a geographic location. This process is the definition of geoprocessing in ArcGIS. The user must open the georeferencing toolbar in ArcGIS. I used the georeferencing tool to georeference raster and CAD data into ArcMap. This method is similar to an image-to-image rectification performed in image analysis software (i.e. ERDAS Imagine). For example, I was able to load a historic aerial photograph that was captured in 1975 and obtained from B&N Coal Company (see Figure 10) without any spatial reference attached to the data.

Figure 10: Historic Aerial Photograph Obtained From B&N Coal Co.

When one loads the raster data in the form of a TIFF file, the file will be loaded in ArcMap but it will have no specific location. In order to give it one the user must set up corresponding control points on the image that one wishes to reference and the layer that one wishes to reference it to. In my study, the reference layer that the geographic coordinates were based on is the already spatial defined 2011 NAIP imagery (WGS 84). It is usually sufficient to select two pairs of control points when geoprocessing. These two points should be well spaced in order to obtain an accurate transformation to the location that is desired. The final historic aerial photograph overlaid on the 2009 imagery can be seen in Figure 11.

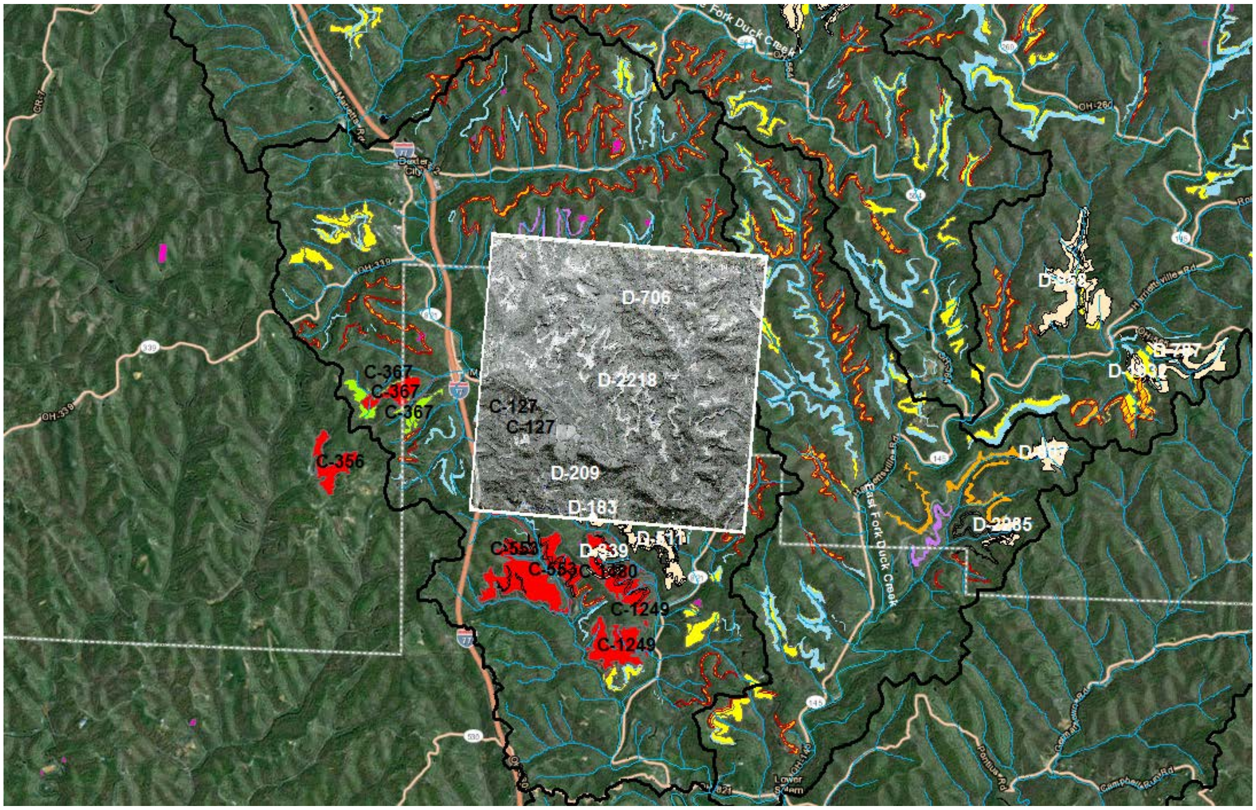


Figure 11: Final ArcMap view with Historic Photo Geoprocessed

Geoprocessing and georectifying images are valuable applications of ArcGIS to the research involved in investigating the impacts of remining. This is the beginning of the process so without this capability no other steps would be possible. One of the key features of geoprocessing in ArcGIS is its ability to automatically select the coordinate system that is already being used in the geo-database. This results in a consistency of spatial data to the same map projected coordinates. This greatly facilitates the data acquisition and analysis project.

4.2 Digitizing in ArcGIS

One of the main tools that a researcher can use in analyzing the Land Use Land Cover (LULC) changes is digitizing in ArcGIS. In my study the LULC changes I am interested in are the amount of abandoned mine land that has been remined in the Duck Creek Watershed. Much of the vector spatial data used in the GIS was digitized from paper maps and aerial or satellite photographs. Digitizing data involved placing a map or photo on a digitizing tablet (a drawing table connected to a computer) and tracing features with a puck, which is a device similar to a mouse. In a variation called heads-up digitizing, features were drawn with a mouse directly on the computer screen by tracing an aerial photo, a scanned map, or other spatial data.

The digitizing function in ArcGIS is important in my analysis of LULC changes with respect to remining of abandoned coal mines (see Figure 12). First, I started viewing a historic image of a location in the watershed prior to the remining movement (circa 1975). The image was then spatially referenced through using the georeferencing application in ArcGIS that was described in the section 4.1. Then I overlaid historic imagery with modern aerial imagery. When the user compares the modern imagery with the historic imagery, one is be able to determine whether remining and reclamation has occurred in the subwatershed. The user can determine whether remining has occurred or not by clues in the picture. For example, if the modern imagery look like a rolling pasture in modern aerial imagery then it is most likely a reclaimed mine site. If it looks to the user that there are still highwalls and pits remaining then the remining has not occurred at that location.

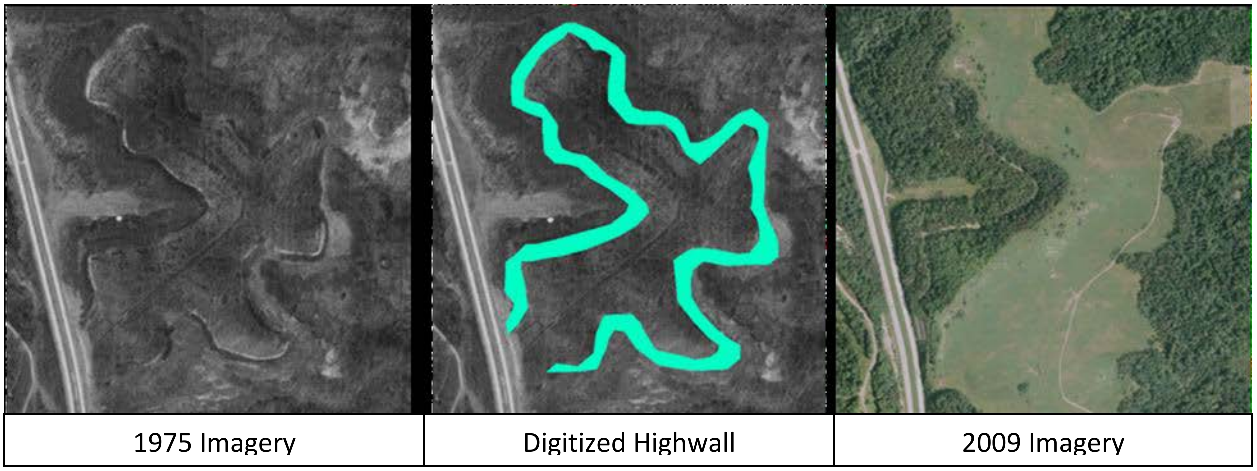


Figure 12: Example of Digitizing in ArcGIS

The classification of the current status of abandoned surface coal mines is subjective to the decision and opinion of the user. Inherently, some user error in the classification process does exist using this method. It is relatively easy to tell when an area has been fully reclaimed or not but what can be difficult is determining whether a site has been partially reclaimed or not. In other words, it can be difficult to determine whether the dangerous pits have been eliminated or not. In some locations in the Duck Creek Watershed, there are abandoned mine sites that have been partially reclaimed. This means that the abandoned mining pits have been reclaimed but the highwalls still remain. This can be the result of State funded Abandoned Mine Land (AML) projects or permit A designation mining that occurred in the state of Ohio. In A designated permits, it was not required of the coal operator to fully reclaim the land that they were allowed to mine. The coal operators were only required to eliminate the abandoned pits at the bottom of the highwalls in the area they extracted the coal from. This process is what is termed partial reclamation.

There are other resources that can be used to assist the user in determining whether the area has been fully reclaimed, partially reclaimed, or not reclaimed at all. A very useful tool in the determination of the location of abandoned strip mines was Ohio 7.5 minute quadrangle topographic maps. These topographic maps were used to verify the location of abandoned strip mines because the locations of abandoned strip mines are shown on these maps. It is a very useful way the double check whether one has digitized all the abandoned strip mines or has missed a few. It can also be a useful tool in verifying the user's intuition that an area looks like an abandoned mine.

Once having determined the designation of the current status of the location of the mine site in question, I then began creating the feature class of the area that has been reclaimed. As the user, I created a feature class of all the polygons or polylines depending on whether the user is digitizing highwalls or mining affected area. Then the user enters edit feature mode and performs a lot of the detailed work. One meticulously maps out, creates, and stores features to be stored in the geo-database. Once the user has created and stored the feature class into the database one can attach a designation to it. The user does this through editing the attribute table associated with that specific feature created.

The ability of ArcGIS to store attributes was a valuable tool in my research. One can store the reclamation status of the respective polygon/polyline, designating it as fully reclaimed area, partially reclaimed area, or unreclaimed area. Other designations can be added to that same feature such as area, permit designation, coal company name, etc. This ability is an asset with respect to performing analysis on the Duck Creek Watershed at a macroscopic level. Using these created attributes attached to the spatially defined features created allowed me to perform statistical analysis not only at a watershed level but also at a sub-watershed level. This allowed me, as the user, to easily perform statistical analysis on the amount of remining in the watershed. The user can then quantify the amount of remining that has occurred through this statistical analysis. This allows the user to calculate the total amount of highwalls that have been reclaimed, the amount of highwalls that remain, the total area of mining area affected, and a whole wealth of statistics that can be beneficial to any study.

As expressed in this section, the ability to utilize the ArcGIS software to digitize plays a crucial role in the analysis of the environmental impacts that remining has had on any watershed. The ability to digitize features on top of spatially referenced aerial images is directly responsible for making it possible to easily quantify the amount of LULC effect that remining has had on the Duck Creek Watershed. Digitizing also makes it possible to manually designate spatial data to features in ArcGIS. This is especially helpful when dealing with data from non-electronic sources that do not automatically load into the user database with spatial data. If the ability to digitize is not possible, then it would be impossible to perform this analysis. Digitizing is a key tool in order to have a complete centralization of relevant data to the project readily accessible for the user to use at discretion.

4.3 – Complete Centralization of Data

An advantage of ArcGIS and a major reason why there is wide use of ArcGIS, or any other GIS software for that matter, is the ability to store a rich collection of spatial data in a centralized location. The venue in ArcGIS that makes this possible in is termed the geo-database. The geo-database is the common data storage and management framework for ArcGIS. It combines “geo” (spatial data) with “database” (data repository) to create a central data repository for spatial data storage and management. It is what allows the user to store GIS data in a central location for easy access and management. (ESRI, 2013a) While assisting researchers at OSU in the investigation of the environmental impacts of remining, one needs to obtain, store, and call upon a wide variety of data. Data needed includes permit data, water quality data historic and current, aerial images in the form of raster data, soil data, political data, and the land cover analysis data created. What was just listed is only a fraction of the data used in the research efforts. As one can imagine, it would be a quite inconvenient to keep this data stored in separate locations. An even bigger inconvenience would be to store and call upon spatial data and represent them on a map. The geo-database in ArcGIS alleviates that pain and saves countless hours in data analysis and produces a way to be able to “see” what data is associated with each feature located in ArcMap.

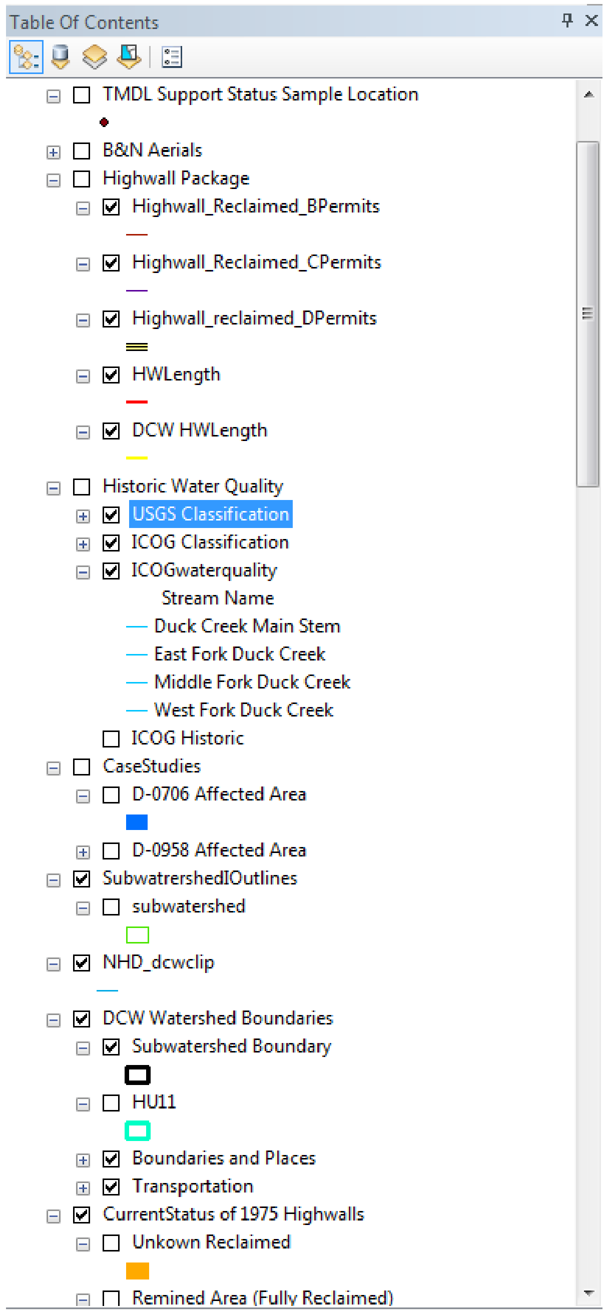
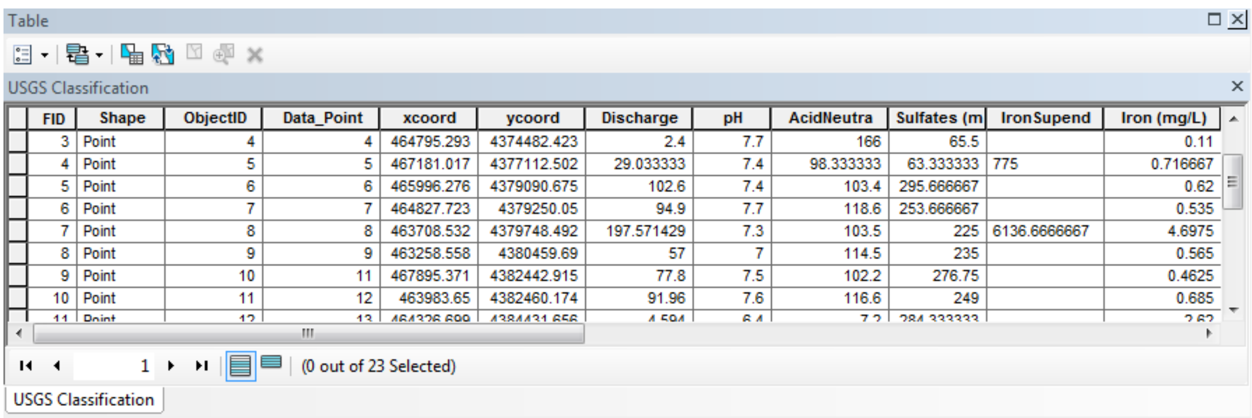


Figure 13: Table of Contents in ArcGIS

The current table of contents in ArcGIS is shown in Figure 13. This is intended to show the diverse amount of data that is involved in my research efforts. There are some data that has been loading into ArcCatalog as shapefiles that have already been created. These types of files are what are normally obtained from ODNR or any other government agency with information pertaining to our research. There are feature files that have been created by me as the user. The features have been digitized and saved as described in Section 4.2. As one can see in the Table of Contents shown in Figure 13 there are point features, line features, and polygon features on it. These features also have data termed attributes stored along with them in an attribute table. An example of an attribute table is shown in Figure 14. It is the attribute table associated listing the attributes of the Industrial Coal Operations Group (ICOG) WQ sample locations. It has been stored as point features with the data listed in Figure 14 associated with it. As one can see, there can be vast amounts of data stored to a class feature so it is very important to be able to keep them all in a centralized location.



Table

USGS Classification

FID	Shape	ObjectID	Data_Point	xcoord	ycoord	Discharge	pH	AcidNeutra	Sulfates (m	IronSupend	Iron (mg/L)
3	Point	4	4	464795.293	4374482.423	2.4	7.7	166	65.5		0.11
4	Point	5	5	467181.017	4377112.502	29.033333	7.4	98.333333	63.333333	775	0.716667
5	Point	6	6	465996.276	4379090.675	102.6	7.4	103.4	295.666667		0.62
6	Point	7	7	464827.723	4379250.05	94.9	7.7	118.6	253.666667		0.535
7	Point	8	8	463708.532	4379748.492	197.571429	7.3	103.5	225	6136.6666667	4.6975
8	Point	9	9	463258.558	4380459.69	57	7	114.5	235		0.565
9	Point	10	11	467895.371	4382442.915	77.8	7.5	102.2	276.75		0.4625
10	Point	11	12	463983.65	4382460.174	91.96	7.6	116.6	249		0.685
11	Point	12	13	464326.699	4384431.656	4.594	6.4	7.2	284.333333		2.62

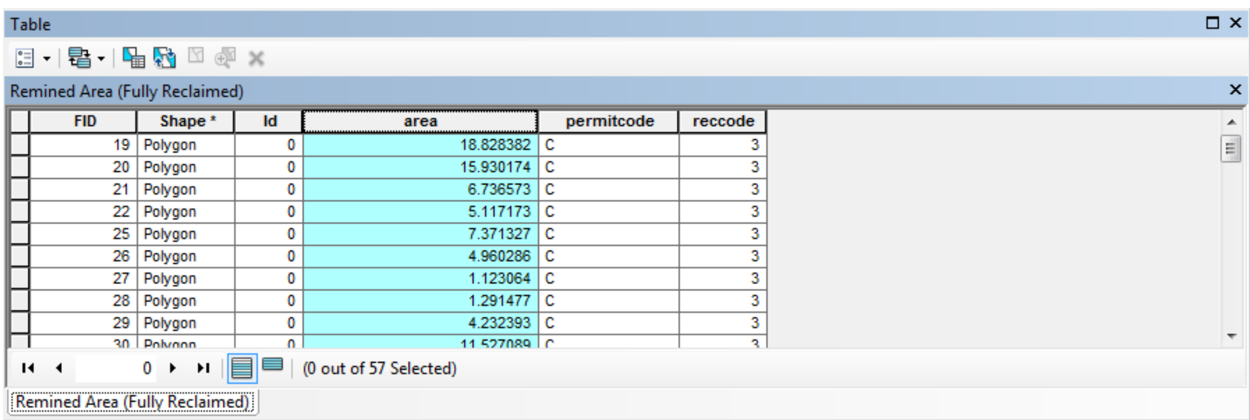
1 (0 out of 23 Selected)

USGS Classification

Figure 14: Attribute table in ArcGIS

Not even all the data used in the project work is listed in the table of contents listed in Figure 13. This is only about a fourth of the data used in ArcGIS. As one can see, it can be a challenge to keep track of all this data. That is where ArcGIS has a substantial effect on my research effort. I can easily store this vast amount of data in one centralized location because of ArcGIS. This location is what is described as the geo-database.

There are many examples of how having all the data spatially consistent and stored in a central location can greatly augment the analysis of the environmental impacts of remining. For instance, one of the main aspects of this research is the amount of remined area in the watershed. Once I loaded the aerial photograph into the geo-database and have digitized the locations of all the area that are remined, I then store what is referred to in ArcGIS as attributes. The attribute table created for the remined area is shown in Figure 15. The FID (File Identifier) and shape columns are automatically created by ArcGIS and cannot be changed or deleted. The rest was added by me for this research effort. The area is calculated by the software when a polygon feature is created.



Table

Remined Area (Fully Reclaimed)

FID	Shape *	Id	area	permitcode	reccode
19	Polygon	0	18.828382	C	3
20	Polygon	0	15.930174	C	3
21	Polygon	0	6.736573	C	3
22	Polygon	0	5.117173	C	3
25	Polygon	0	7.371327	C	3
26	Polygon	0	4.960286	C	3
27	Polygon	0	1.123064	C	3
28	Polygon	0	1.291477	C	3
29	Polygon	0	4.232393	C	3
30	Polygon	0	11.527089	C	3

0 (0 out of 57 Selected)

Remined Area (Fully Reclaimed)

Figure 15: Attribute table created for remined area feature class with Area column highlighted

ArcGIS automatically stores the area values of the areas of polygons that were digitized and stored as representing fully reclaimed area. Since I have all those area calculations, I calculated the amount of fully reclaimed area in the entire watershed by using the built-in statistical functions in ArcGIS. I was able to determine that there has been 553 acres of reclaimed area as a result of remining in the Duck Creek Watershed. The statistical analysis window for the area column of the attribute table is shown in Figure 16. For my research purposes, I am primarily concerned with the sum of the area column because that is the determination of the total amount of remined area in the watershed.

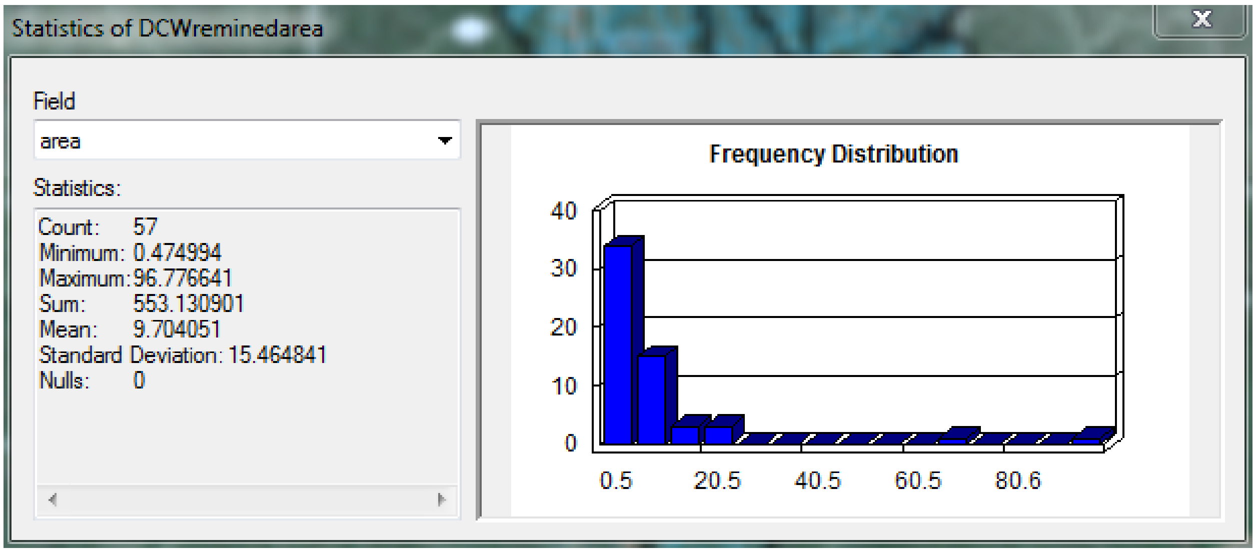


Figure 16: Statistical Window for Remined Area in the Duck Creek Watershed

ArcGIS has a very extensive collection of selection options. The two main types of selections one can perform are selection by attributes and selection by location. The selection by attributes function uses Structured Query Language (SQL). SQL is a powerful language one uses to define one or more criteria that can consist of attributes, operators, and calculations. (ESRI 2013b) For example, if it was desired to know which WQ samples taken from the Industrial Coal Operations Group (ICOG) report where the pH was recorded to be lower than 4.5. One would select the water quality sample locations with this expression: pH < 4.5. Then all the water quality sample locations that have a recorded pH less than 4.5 attached to the feature will be selected.

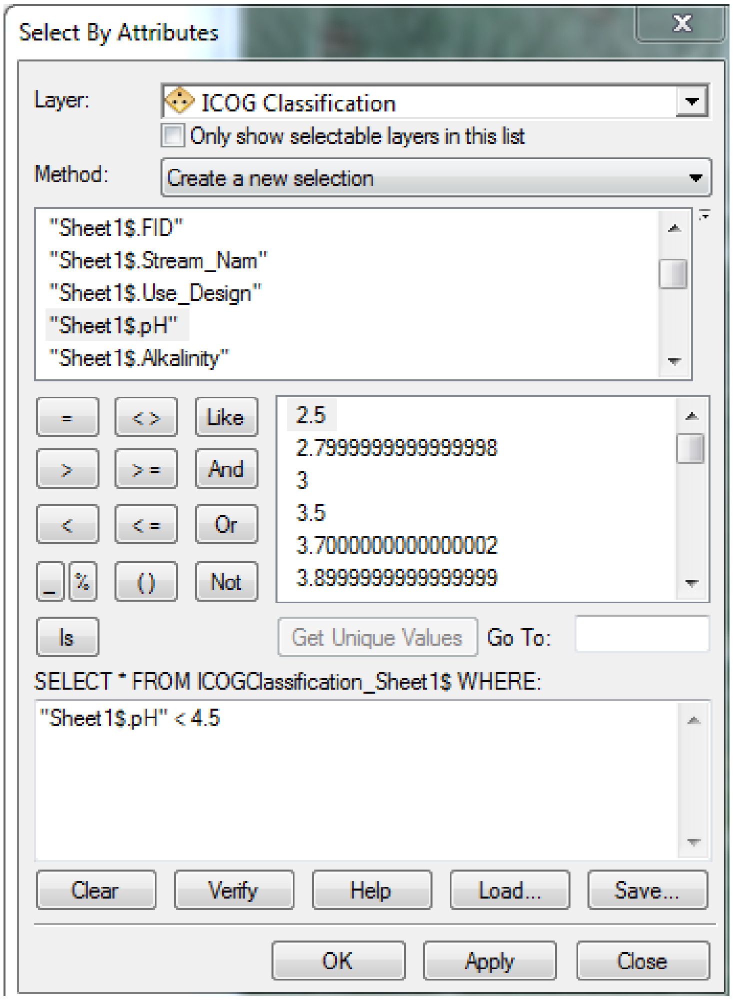


Figure 17: Selection by Attributes

The select by attributes dialog box is shown in Figure 17. Here one can select any condition for any feature and the ArcGIS will select those features and not the rest. As a user one can also determine the number of sample locations that met that condition and one can determine where those points are located. The result of the selection by attributes is shown in Figure 18. In ArcMap, one can see the point features representing historic WQ sample locations represented as orange triangles. The data points that were selected are shown in light blue. From this map one can determine where the most negatively affected streams are located as a result of historic mining.

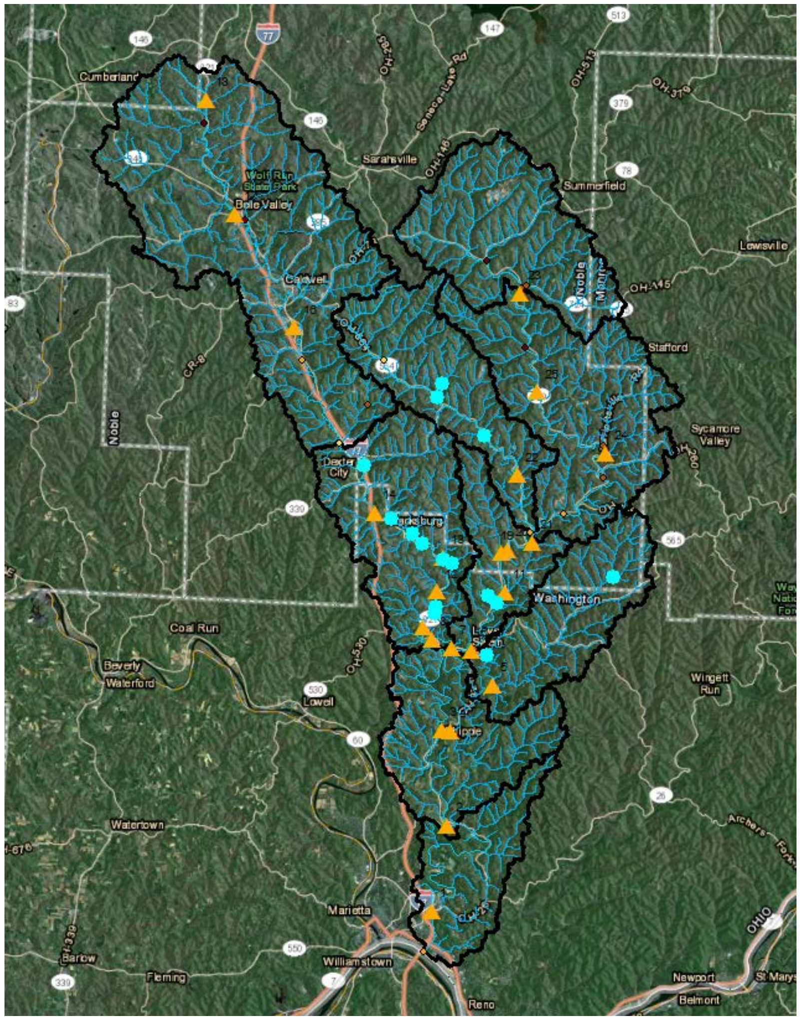


Figure 18: ArcMap view with selection by attributes applied

From this information discovered and conveniently shown in ArcMap, scientists, researchers, engineers, and state officials can infer which areas had the worst effect on the water quality of headwater streams as a result of historic coal mining. This type of information can be used for future decision making with regards to where a coal operator should start the next remining/reclaiming project.

Selecting data by attributes is not the only method for selecting data however. Another method of selecting data in ArcGIS is selection by location. The selection by location tool allows the user to select features based on their location relative to features in another layer. (ESRI, 2013b) For instance, if one wanted to know how many mine sites are in proximity to a town, one could select all of the mines that are within a certain radius of that town. The selection by location tool has greatly assisted my research efforts, especially with regards to my sub-watershed analysis. So far, the analysis that has been described in this thesis has been for the Duck Creek Watershed as a whole. However, The Duck Creek Watershed is made up of 9 smaller watersheds. These smaller watersheds that make up the Duck Creek Watershed are termed as sub-watersheds. It can be beneficial analyze the Duck Creek Watershed at a sub-watershed view. This microscopic perspective study of Duck Creek can lead to the discovery of a wealth of information pertinent to my study. The locations within the subwatershed that has the most mining or remining that has occurred in it. This can assist in the determination of the location of new research study locations or mining sites to remine.

In order to illustrate the selection by location tool, I will revisit the remined area feature class. The difference is this time I am curious to know the amount of area that has been remined in a subwatershed. This type of operation can be performed on any subwatershed but I am going to calculate the remined area in what we termed Subwatershed #3 (Buffalo Run Subwatershed). A map of Subwatershed #3 is shown in in Figure 19. The current status of pre-law mining areas is shown in the map below along with mining affected area by permit designations. The historic WQ data that was mentioned previously is also shown on the map. The historic WQ data that was mentioned previously is also shown on the map.

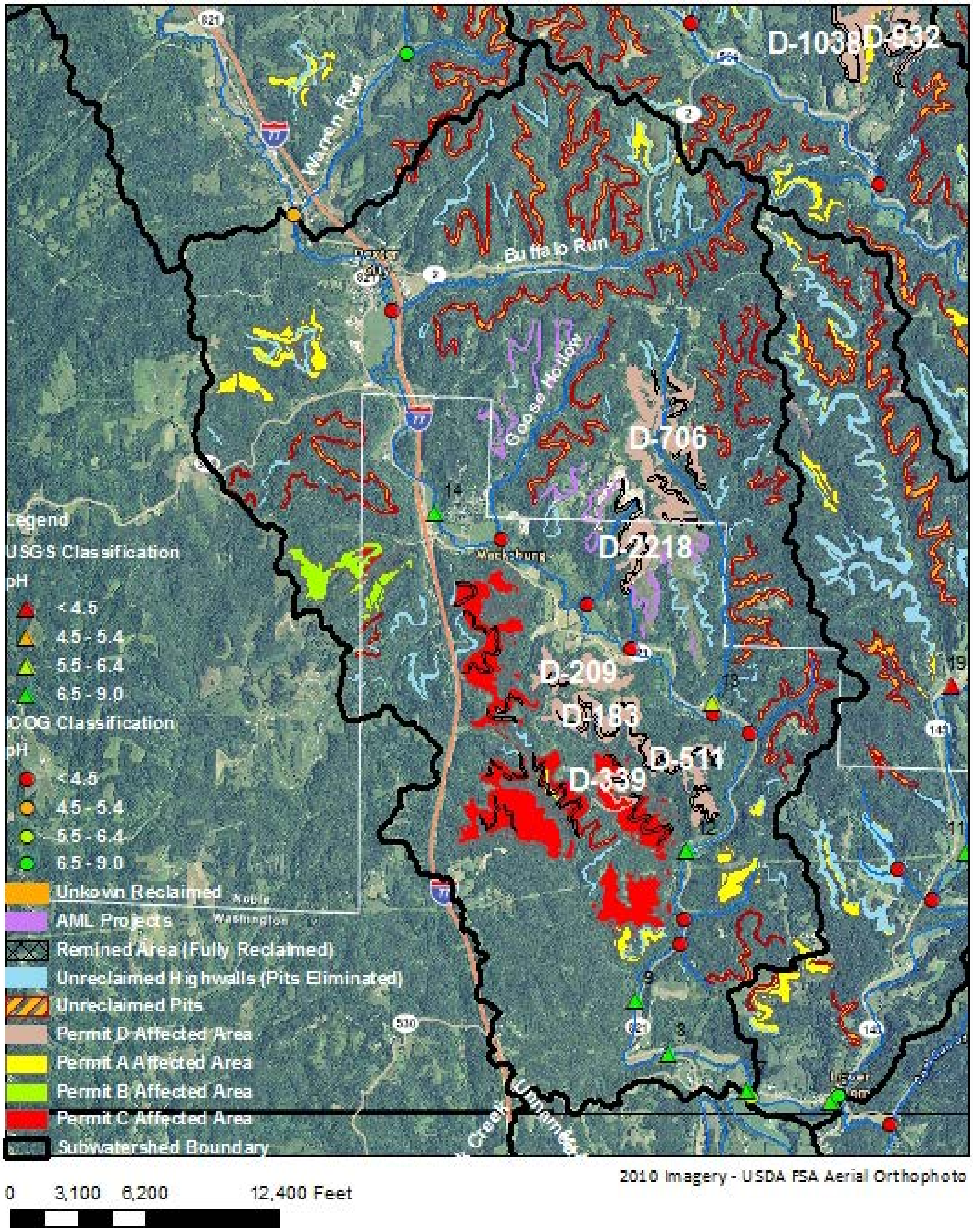


Figure 19: Map of Subwatershed #3 (Buffalo Run)

.

If it is desired to know the amount of remined area that is within Subwatershed #3, one can use the select by location tool. The select by location tool is shown in Figure 20. It shows numerous ways to select features with respect to their spatial properties. For the purposes of determining the amount of remined area in the subwatershed, one first must select the subwatershed. Then one can use the settings shown in Figure 20. Subwatershed Boundary is the source layer. The source layer is the area from which the user is selecting features of the target layer. The target layer is simply the feature class that one wants to select, so in my case it will be the Remined Area feature class. The spatial selection method for the target layer feature is to have their centroid in the source layer feature. This is just one of selection methods that the user can select. Other selection methods include: intersect the source layer feature, are within a distance of the source layer feature, contain the source layer feature, and others.

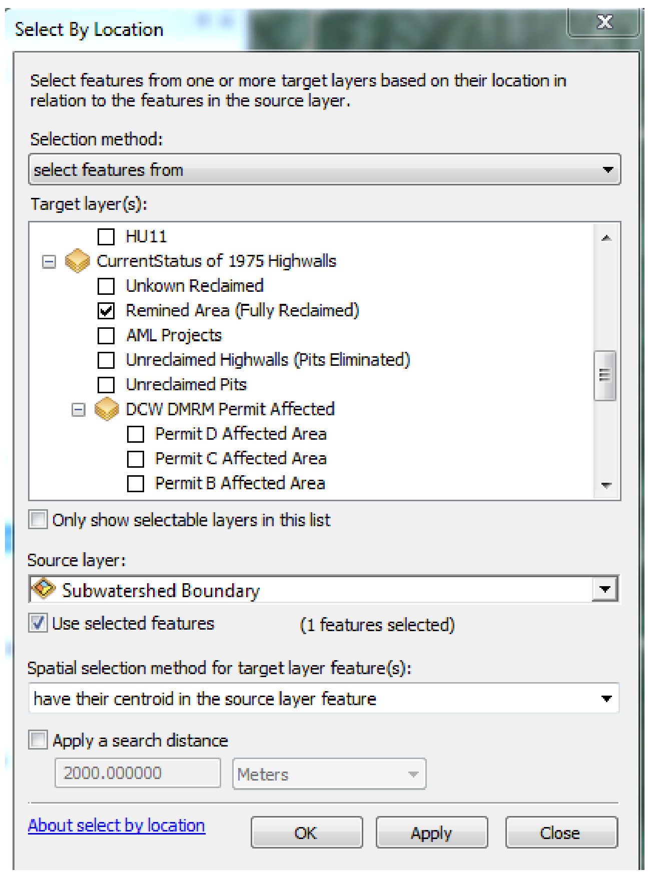
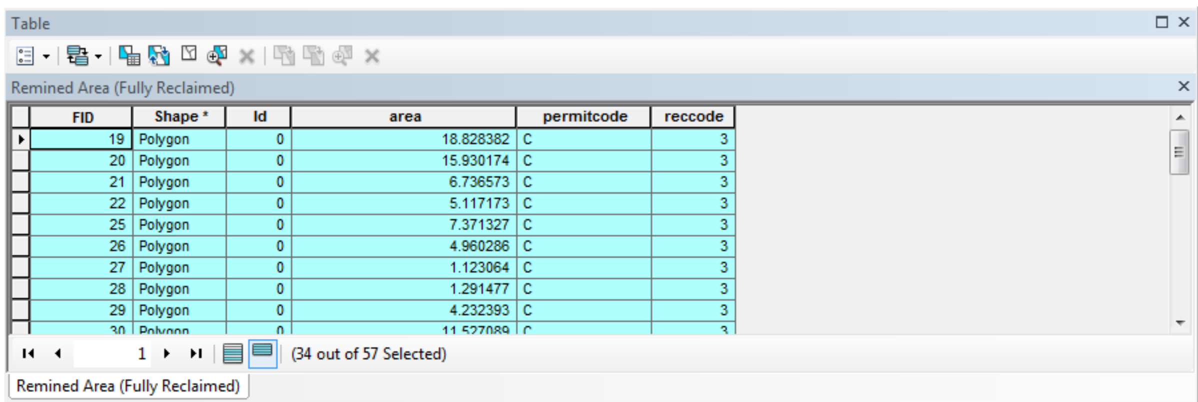


Figure 20: Select by Location Dialog Box

Once the selection by location shown in Figure 20 was performed, ArcGIS selected all the remined area features that are located within subwatershed #3. Now some statistical analysis can be performed similar to the way I calculated the total remined area in the Duck Creek Watershed. The only difference is now one only runs the statistical analysis on the selected features instead of all the features. This process is shown in Figures 21 and 22. If one looks at Figure 21 one can see that 34 out of the total 57 Remined Area features are selected. It can also be seen that about 213 acres of remined area in Subwatershed #3 (See Figure 22).



Table

Remined Area (Fully Reclaimed)

FID	Shape *	Id	area	permitcode	reccode
19	Polygon	0	18.828382	C	3
20	Polygon	0	15.930174	C	3
21	Polygon	0	6.736573	C	3
22	Polygon	0	5.117173	C	3
25	Polygon	0	7.371327	C	3
26	Polygon	0	4.960286	C	3
27	Polygon	0	1.123064	C	3
28	Polygon	0	1.291477	C	3
29	Polygon	0	4.232393	C	3
30	Polygon	0	11.527089	C	3

1 (34 out of 57 Selected)

Remined Area (Fully Reclaimed)

Figure 21: Attribute Table Containing Selected Remined Area Features

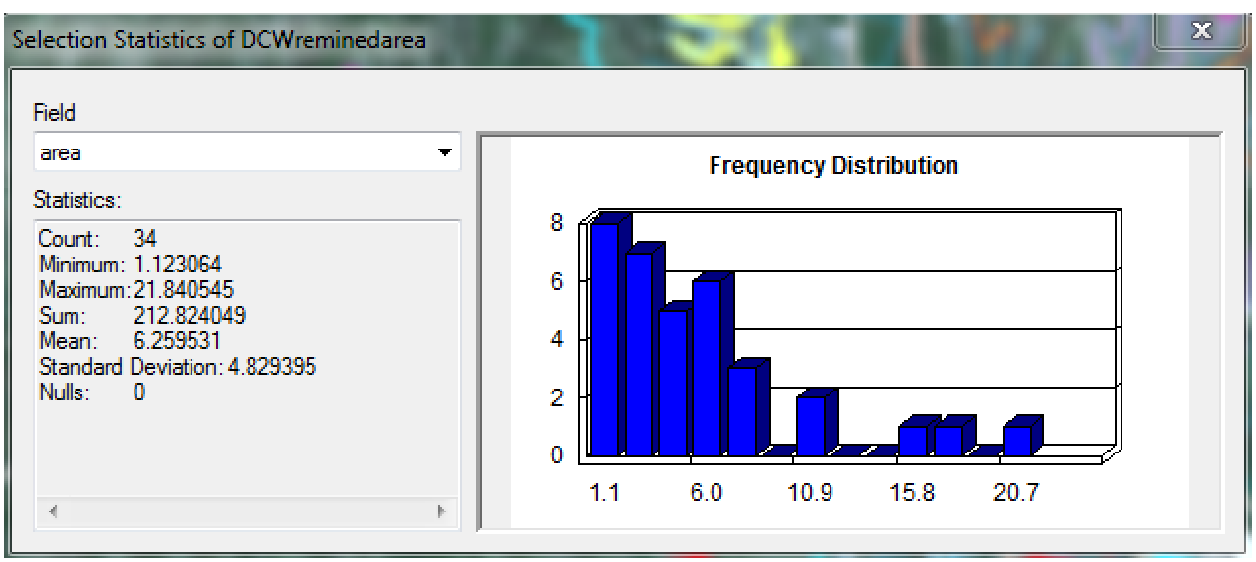


Figure 22: Statistical analysis of Remined Area Within Subwatershed #3

From performing selection statistical analysis we can determine that about 213 acres of dangerous abandoned mine land has been reclaimed as a result of remining. From this we can see ArcGIS's ability to house a location for a complete centralization of data is one of its best features. This ability was intended to be demonstrated in this chapter through the applications to my research. In the geo-database one can easily look up the data stored linked with a feature in ArcGIS. This data can be found in the attribute table and every feature class has an attribute table. Simple statistical analysis can be performed on columns in the attribute table. The statistical analysis function is useful in the research efforts because it allows us to calculate the total area that has been remined in the area. This is a good example of how we use this tool but it is not the only way that this tool has assisting me in this research effort.

4.4 –Visual Interpretation of Data Through ArcMap

One of the best capabilities of ArcGIS and one of the reasons for its creation is its map making abilities. GIS is revolutionizing the way in which maps and map-related data are stored. Throughout history there have been certain inventions that have sparked a wave of change. The impact of GIS on cartographers, planners, engineers, surveyors, and others is comparable to the impact computers first had on accountants and administrators in the 1970s, the impact word processing had on secretaries and typists in the 1980s, and the impact the Internet had on marketing and sales managers in the 1990s. (George B. Korte, 2001) ArcMap is the specific ArcGIS component that I am using for my research. ArcMap is an application for displaying maps and investigating them, for analyzing maps to answer geographic questions, and producing maps that make analysis persuasive. The ArcMap application window consists of a map display for viewing spatial data, a table of contents for listing the layers shown in the display, and a variety of toolbars for working with the data. (Ormsby, 2009) Through ArcMap, it is possible to produce detailed maps.

Mapmaking used to be a long tedious process. Gathering the data, making all other preparations, and then drawing maps with the highest possible amount of detail and precision could take up to 7 years before the advent of GIS. Now, once one has all the data desired, a detailed map can be produced with a few clicks of the mouse. This feature allows one to produce professional quality maps on short notice. ArcMap has several built-in templates to assist with the quick production of accurate, informative, and aesthetically pleasing maps. Whether it be the location of permits issued in the watershed or the historic amount of sulfates that is desired to be augmented through the maps, these reliable maps can be created and manipulated by the user in ArcMap. This capability has been useful in the analysis of the environmental impacts on the Duck Creek Watershed in a number of ways.

First let us say I want to produce a map of the Duck Creek Watershed. Obviously, it is a good idea to have a visual representation of the place that is the focus of my study. In ArcMap this can be performed assuming that all the data is already loaded into ArcGIS. There are two main views that one can work out of in ArcMap: Data View and Layout View (See Figures 23 and 24). Each view allows the user to view and interact with the map, but in different ways. Data view provides a geographic window for exploring, displaying, and querying the data on one's map. The user works in real world coordinates and measurements in data view. In layout view, one works with the map layout elements, such as titles, north arrows, and scale bars, primarily in page space (typically in inches or centimeters) except when one is interacting with a data frame in the user layout. (ESRI, 2013c) In the layout view, one can work with the data frame and also work on the user's map formatting but the data view area is much smaller. In data view, the user has a bigger view to work with but cannot manipulate any annotation options of the map (i.e. scale, north arrow, legend, title, etc.)

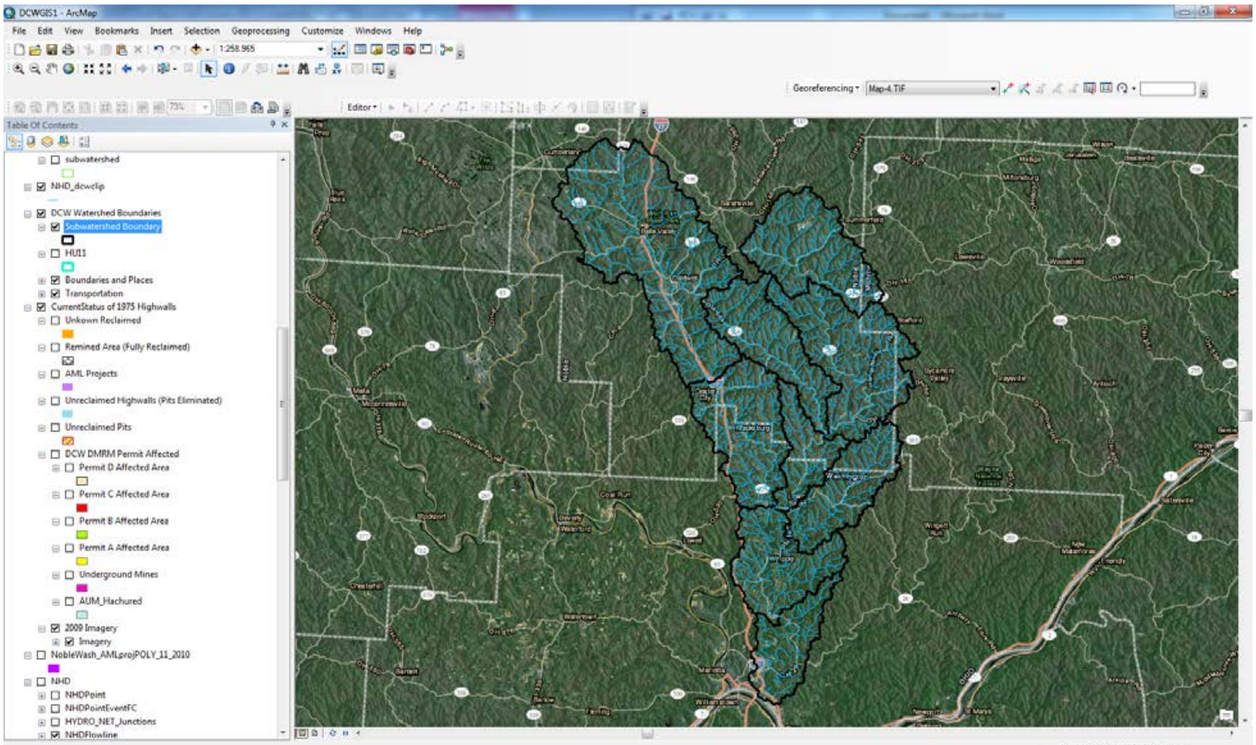


Figure 23: Data View of ArcMap

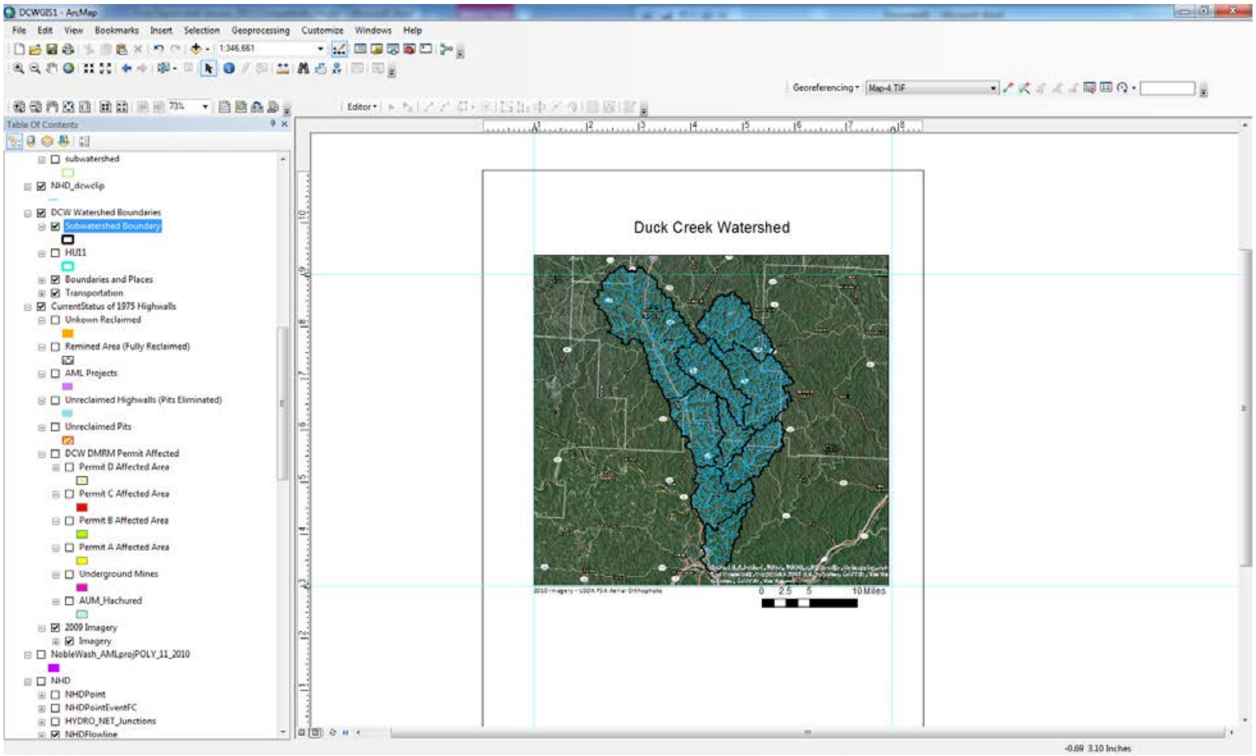


Figure 24: Layout View of ArcMap

The user can manipulate and change the formatting until an acceptable map can be created in the layout view. ArcMap has a vast amount of ways and techniques that the user can format the map to user preferences. A scale bar, legend, north arrow can all be added and changed in this view. Also borders can be added around the map or the whole mapping area. Once an acceptable map is ready one can then use the export map command (located in the file tab) to save the map as an image file which then can be printed or inserted into a PowerPoint presentation or added to a report. An example of a basic map of the Duck Creek Watershed is shown in Figure 25.

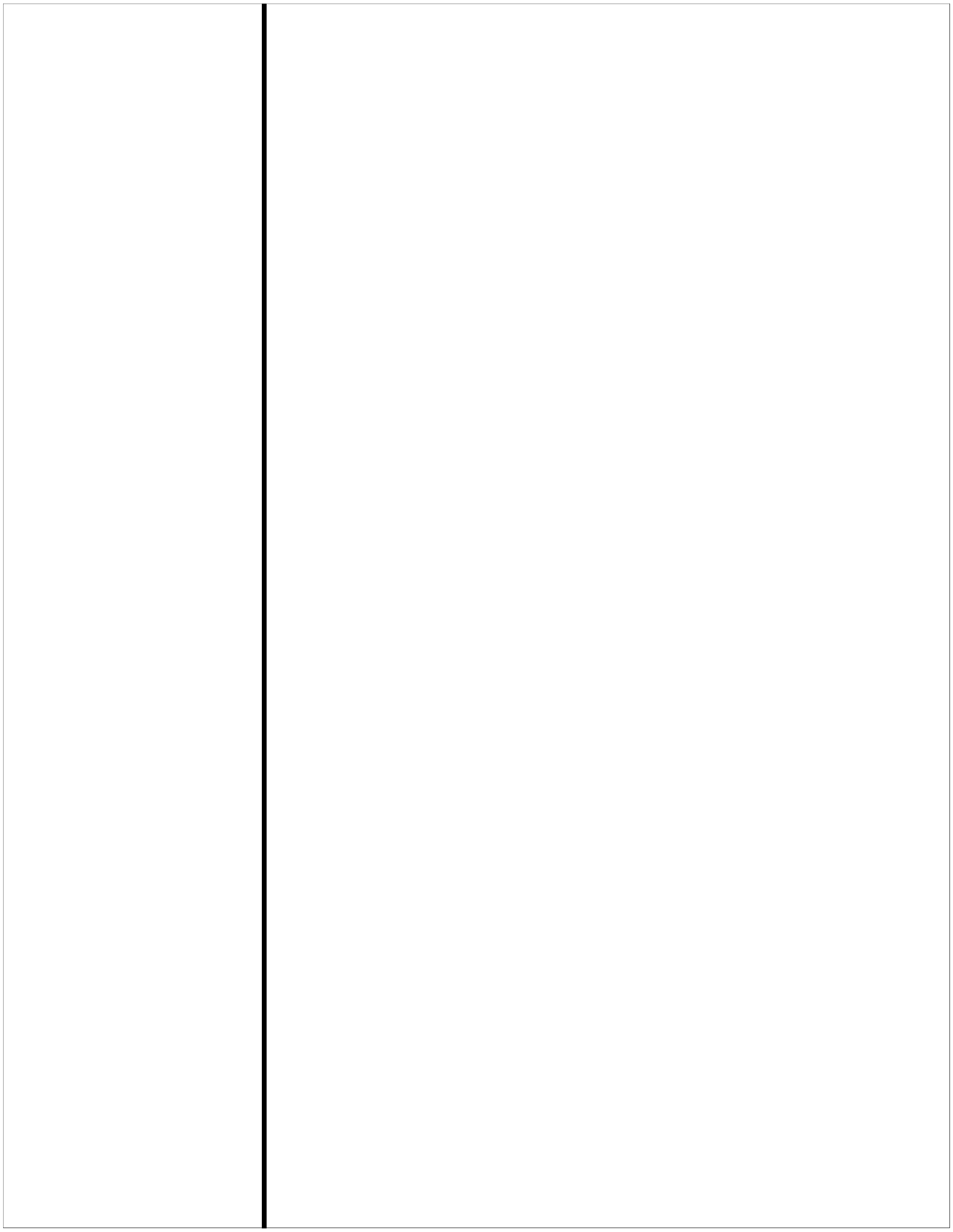


Figure 25: Finished Product of a Map of the Duck Creek Watershed

Not only can ArcMap be used to make a basic map of the Duck Creek Watershed, but it can show specific aspects of the watershed that are of concern to us as researchers and scientists. For my study dealing with the environmental impacts to the stream caused by mining in the watershed, a Total Maximum Daily Load Report (TMDL) is useful to extract information from. The Clean Water Act and USEPA regulations require that TMDLs be developed for all waters in the section 303(d) lists. A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. Ultimately, the goal of Ohio's TMDL process is full attainment of biological and chemical Water Quality Standards (WQS) and, subsequently, delisting of water bodies from the 303(d) list. (Ohio Environmental Protection Agency Division of Surface Water, 2003) In 2003 The Ohio Environmental Protection Agency (OEPA) issued a TMDL report for Duck Creek. In this report was a table of what is considered impaired streams in the Duck Creek Watershed by the OEPA. A portion of the table is listed in Table 1 below.

Table 1: Supporting Status of Streams in the Duck Creek Watershed

Ohio Environmental Protection Agency Watershed TMDLs			Duck Creek		
Stream Segment	**Support Status**	**Designated Use[a]**	**Cause**	**Source**	**TMDL Included in This Report**
West Fork East Fork Duck Creek	Partially Supporting	WWH	Aluminum Manganese Iron	AMD AMD AMD	/ / /
East Fork Duck Creek Tributary (RM 5.73)	Nonsupporting	WWH	Aluminum Iron Manganese Siltation	AMD AMD AMD AMD	/ / / /
East Fork Duck Creek Tributary (RM 4.15)	Partially Supporting	WWH	Siltation Aluminum	AMD AMD	/ /
Schwab Run	Partially Supporting	WWH	Siltation	Pasture land	/
Greasy Run	Partially Supporting	WWH	Siltation	Pasture land	/
Elk Fork	Nonsupporting	WWH	Aluminum Manganese Nutrients	AMD AMD	/ /
Flag Run	Partially Supporting	WWH	Aluminum Iron	AMD AMD	/ /
Road Fork	Partially Supporting	WWH	Siltation Aluminum Iron Manganese	Pasture land AMD AMD AMD	/ / / /
Barnes Run	Partially Supporting	WWH	Aluminum	AMD	/

[a] EPA Use Designations: WWH=Warmwater habitat; EWH=Exceptional warmwater; LWH=Limited warmwater habitat.
[b] AMD=acid mine drainage.
[c] Draft 2002 Section 303(d) listings for the watershed are pending approval by USEPA.
[d] RM=river mile.

Now the user can go through the process of creating a feature class, loading all the data in the table into ArcGIS, and performing all other necessary steps in order to get a presentable presentation of the data on a map. A finished product of this map can be viewed in Figure 26. As one can see, some advanced feature labeling was employed in the production of this map. This map provides a visual representation of the data shown in Table 1. From this map one can determine a few facts about the watershed that might not have been noticed otherwise. For example, one can tell that most of the streams source of impairment is AMD. One can also determine and have a visual of where in the watershed are the impaired streams located.

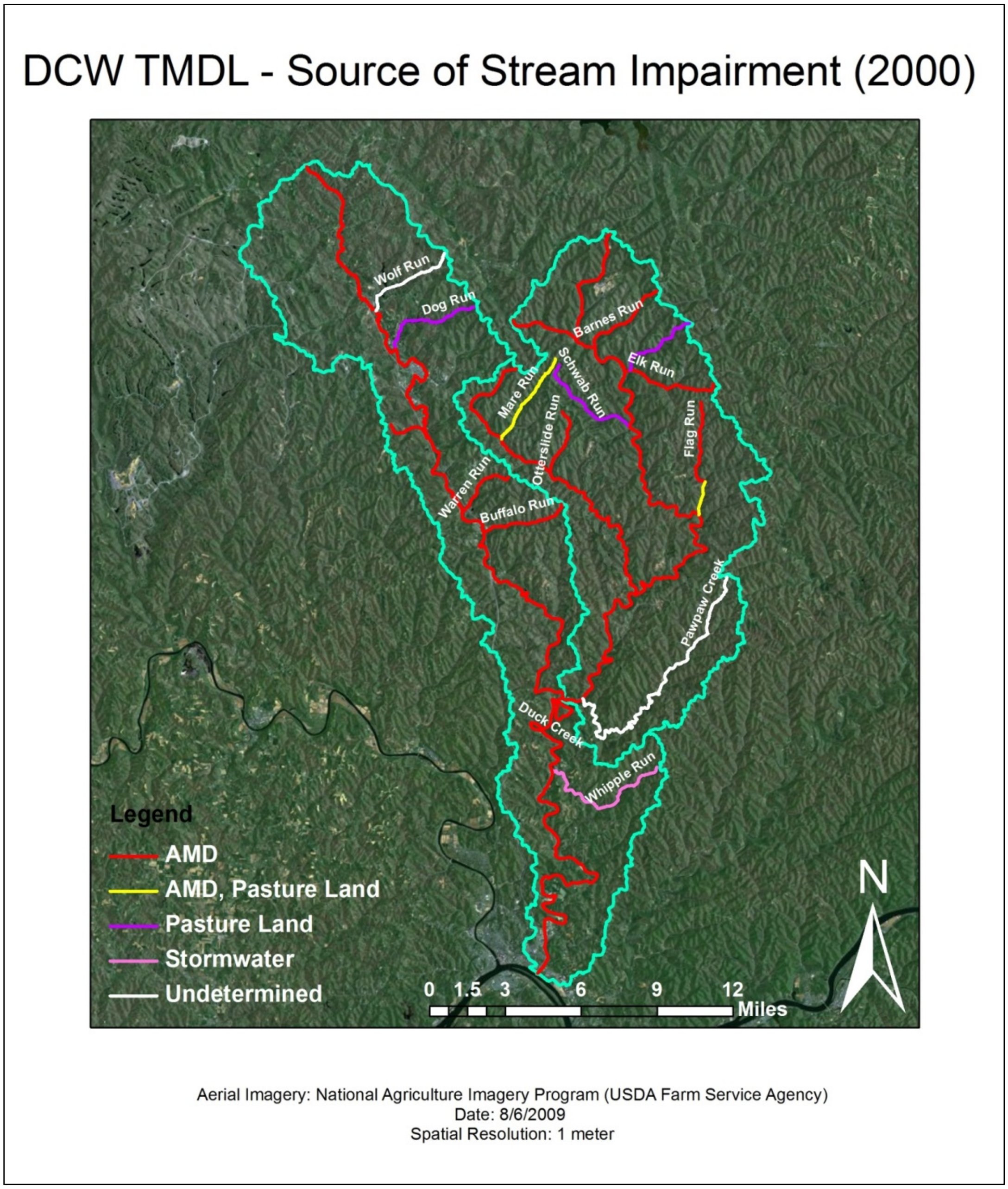


Figure 26: Duck Creek Watershed source of stream impairment

The user can also configure a map in ArcMap to visually represent the given amount of a parameter with respect to other areas. This is helpful with respect to my study because there are certain contaminants that are present in the streams that have been affected by mining. A few of these contaminants include sulfates, iron, and manganese. In ArcMap it is possible to represent the data on a map. Below in Figure 27 a map of the amount of sulfate in water that was sampled by two different agencies and two different time periods. These two data water quality data sets are from the Industrial Coal Operators Group (ICOG) report and the United States Geological Survey (USGS) interactive website

The ICOG data was extracted from an earlier report released in 1974 known as the Land Reborn Report. The water quality data used in this report was sampled between the years 1965-1972. The USGS water quality data was obtained from the USGS interactive web page. The water quality data extracted from the website was sampled between 1982-1985. In ArcMap it is possible to represent each data point by proportionally sized symbols. The USGS and ICOG sample locations are represented by triangles and circles respectively. From this map one can easily determine which streams had the highest sulfates amount which can lead one to the conclusion of which streams had the most negative effect from historic mining. Figure 27 shows the amount of sulfates reduced drastically in the amount of time between the samples were taken. This shows that there has been a huge improvement in the watershed. Stream quality in streams containing mining improves due to three phenomenons: Remining, AML projects, and attenuation. This helps from a regulatory perspective because it can be evidence that remining has a positive impact on the water quality of a watershed.

Figure 27: Sulfate Totals

The mapping capability of ArcGIS is an asset to researchers. A quick representation of different data in a different location can be created in less than a half hour. I have only scratched the surface of the different types of map and data presentation that one can create. The user can make permit locations, mine locations, remined area, case study locations, and much more. These maps can serve as an invaluable asset to researchers, operators, engineers, and bureaucrats alike.

Chapter 5 – Summary and Conclusions

5.1 Summary

Using the ArcGIS method described in this thesis, it is feasible to quantitatively evaluate the impact that remining has on a watershed. ArcGIS has been shown to be a valuable tool in the investigation of environmental impacts remining on the Duck Creek Watershed located in Noble and Washington Counties. I utilized the historic aerial photography (circa 1975) and modern satellite imagery (circa 2011) through geoprocessing in ArcGIS. By using these different images and a few other resources like topographic maps and mining maps, it was possible for me as the user to digitize or "draw" new feature classes in ArcGIS. This new feature class was then used to determine the amount of area that has been remined. The total amount of highwall that has been eliminated through remining was also calculated. This is possible because of the geo-database in ArcGIS. The geo-database gives a venue to house all the data. This allows for a complete centralization of data. This data was arranged and displayed though ArcGIS's ArcMap and conclusions were made from these maps.

5.2 Conclusions

Through the use of ArcGIS, it was determined that it is possible to comprehensively evaluate the impacts of remining on a watershed. It is evident that ArcGIS has made this analysis possible. A few of the advantages that ArcGIS includes but are not limited to: spatial georeferencing, digitizing in ArcGIS, centralization of relevant data, and visual interpretation of data. Georeferencing has allowed me to introduce aerial photography and maps of the area of interest to my study by keeping them all on a consistent projected coordinate system. It also allowed me to assign spatially coordinates to a scanned map or aerial photograph. This is what allowed me to analyze and determine the Land Use Land Cover (LULC) changes that have occurred as a result of remining. I then determined what land has been remined then draw and store this information in a geo-database through a process called digitizing. This capability allowed me to record the location and quantify the amount of land that has been remined. This information was stored in the geo-database along with all other relevant data to my study. This centralization of relevant data allowed me to easily find, compare, and analyze data through a various different selection techniques. Once I decided what data that I wanted to create a visual interpretation for, ArcGIS allowed me to create detailed maps of the area of interest. Map-making used to be a long tedious process that has been made easier by using ArcGIS. For example, it was possible to display all the current status of pre-1975 mine land, the permit designation, and WQ sample locations all on the same map in ArcGIS.

5.3 Future Work

Some future work that can be taken on as an extension of this study is to use ArcGIS to do a detailed study of stream quality and stream characteristics. As the Duck Creek Watershed was being studied Mauger developed a fantastic template for determining the amount of land that has been reclaimed as a direct result of remining. However, when I was looking at and examining water quality data in the watershed, I found that there was not a sufficient amount of recent water quality data to see a long term improvement in the watershed. There are a few locations where one can obtain water quality data from coal operators. Under current mining laws coal operators are required to take water quality samples before and after mining. There is 2000 TMDL water quality data obtained but the TMDL water quality sample locations are not in proximity to the historic water quality sample locations that can be obtained. It would be helpful to study the long-term impact that all the human activity, including remining, has had on the Duck Creek Watershed. With a new detailed stream study, it would be possible to determine this impact. Also, the method of using ArcGIS described in this thesis can be used as a model to study other the coal bearing regions in Ohio along with other coal bearing regions in the world. This is an accurate process for determining the Land Use Land Cover (LULC) changes regarding remining.

References

Bruns, D. A. (2005). Macroinvertebrate response to land cover, habitat, and water chemistry in a mining-impacted river ecosystem: A GIS watershed analysis. Aquatic Sciences, 403-423.

Chrisman, N. (1997). Exploring Geographic Information Systems. New York: John Wiley and Sons.

Crowell, D. L. (1987). GeoFacts No. 15, ODNR, Division of Geological Survey.

Environmental Expert S.L. (2013). Environmental Expert. Retrieved March 1, 2013, from environmentalexpert.com: http://www.environmental-expert.com/soil-groundwater/gis/companies/location-usa

ESRI. (2013a). ArcGIS. Retrieved March 1, 2013, from arcgis.com: http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//00660000043q000000

ESRI. (2013b). ArcGIS Desktop Help. Retrieved February 23, 2013, from Environmental Systems Research Institute: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?Topicname=Using_Select_By_Attributes

ESRI. (2013c). ESRI Web Page. Retrieved February 23, 2013, from www.esri.com: http://www.esri.com/software/arcgis/geodatabase

George B. Korte, P. (2001). The GIS Book. Albany: On Word Press.

Hill, L. L. (2006). Georeferencing: The Geographic Associations of Information. Cambridge, Massachusetts: MIT Press.

Industrial Coal Operations Group. (1980). An Environmental Analysis of Ohio Surface Waters in Watersheds Containing Abandoned Coal Mines. Columbus, OH.

Mauger, N. S. (2010). Impacts of Reclamation and Remining on Watersheds of Pre-Law Legacy Coal Mines. Columbus, OH.

Oguchi, T. (2000). River Water quality in the Humber catchment: an introduction using GIS-based mapping and analysis. Science of the Environment, 9-26.

Ohio Environmental Protection Agency Division of Surface Water. (2003). Total Maximum Daily Loads for Duck Creek. Columbus,OH.

Ormsby, T. (2009). Getting to Know ArcGIS Desktop, 2nd Edition. Redlands, CA: Esri Press.

Skelly and Loy. (1973). Land Reborn: Technical Report for the Board on Unreclaimed Strip Mined Lands Study. Columbus.